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BRL

CONTRACT 169

FINAL REPORT

UPPER ATMOSPHERE WINDS FROM GUN LAUNCHED VERTICAL PROBES

(Includes
Barbados, 21-22 June 1967
Yuma, 12 June 1967)

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SPACE INSTRUMENTS RESEARCH, INC.

BRL CONTRACT 169

FINAL REPORT

UPPER ATMOSPHERE WINDS FROM GUN LAUNCHED VERTICAL PROBES

Includes
(Barbados, 21-22 June 1967)
(Yuma, 12 June 1967)

Prepared for

Commanding Officer
USA Aberdeen Research & Development Center
ATTN: AMXRD-XSE
Aberdeen Proving Ground, Maryland 21005

Contract No. DA-01-009-AMC-169(X)

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SPACE INSTRUMENTS RESEARCH, INC.
Atlanta, Georgia

AUGUST 1968

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NOTE: The wind vector as given in this report is considered to point in the direction toward which the wind is blowing, (that is, a west wind is toward the west). Most meteorologists are accustomed to a 180^{o} difference, (that is, a west wind is from the west).

INTRODUCTION

For several years upper atmospheric winds over the lower West Indies have been studied by firing high altitude ballistic probes from a specially modified sixteen-inch naval gun. The installation of a similar 16" gun at Yuma Proving Ground, Arizona, early in 1966 has made possible a similar study of winds in this region. These firings are being carried out by the U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, under the direction of Dr. Charles H. Murphy, and by the Space Research Institute of McGill University, Canada, under the direction of Dr. G.V. Bull.*

Atmospheric winds are studied by releasing chemical trails from the gun-fired probes during the upper portion of their trajectories. To date, the primary chemical which has been released is trimethyl aluminum (TMA). TMA produces a chemiluminescent glow in regions of the atmosphere above 85 kilometers, thus allowing the trails to be photographed while being distorted by upper atmosphere winds. The photographs are then reduced to provide wind information by Space Instruments Research, Inc. (SIR), using computer techniques.

The purpose of this report is to summarize results of these studies for the period from June 21 through June 22, 1967, and June 12, 1967. A "Table of Trail Information" is given on page 20 and lists the trail number, shot number, date, time and altitude interval. Previous results for winds over Barbados, West Indies,

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are covered in Technical Reports No. 1, 2, 3, 5, 8, and 9. Technical Reports No. 4, 6, and 7 cover previous results for winds over Yuma, Arizona. Included in this report are ground plots for all previous shots that had both an up and down trail. The ground plots are divided into two sections: (1) the trails formed at Barbados, and (2) the trails formed at Yuma. Trail information for all of the shots covered in the ground plots can be found in earlier BRL reports. Only shots with both an up and down trail are included.

DATA ACQUISITION

The chemical trails are formed almost vertically over the Island of Barbados (longitude 59.4°W, latitude 13.0°N) and extend from an altitude of approximately 85 kilometers through apogee. The Yuma trails are formed almost directly over the gunsite (longitude 114.3°W latitude 32.9°N) and extend from an altitude of approximately 85km through apogee. In some firings, TMA is also released on the down leg of the trajectory. To the unaided eye, the chemical release first appears as a straight white trail resembling a jet contrail. Within a minute or so, the trail is distorted into strange shapes by the upper atmospheric winds and fades from view within approximately fifteen minutes after initial release.

Space Instruments Research has established eight photographic triangulation stations on the Islands of Barbados, St. Vincent, Grenada, and Tobage, with two sites per island. These sites are located to the west and south of Barbados at distances of 190 to 290 kilometers (see Figure 1). While only one site on each of two islands is required for data reduction purposes, the eight sites have been found desirable because of cloud conditions in the area.

Three photographic triangulation stations have been established at Yuma and Gila Bend, Arizona, and Blythe, California. These sites are located at distances of up to 150 kilometers from the gunsite (see figure 2).

Equipment at each site, built by SIR, consists of a camera

unit containing two seven-inch focal length cameras mounted on a concrete pedestal, and an electronic control unit. Cameras are automatically pulsed to take exposures of 3, 6 and 12 seconds duration every 30 seconds.

Since commercial power is either unreliable or unavailable at many site locations, SIR has developed a battery operated 115-volt power supply for the control equipment. The power supply is tuning-fork controlled and provides 60 cycle power with an accuracy of 0.005% for the camera programmer so that pictures can be taken simultaneously at each site. A data block containing 24 tiny lights, mounted in each camera unit, records time, firing number, and site information in the corner of each frame of film.

A short wave radio net connecting all sites and the launch control center has been installed by SIR to enable the launch control officer to be informed of weather conditions at the sites and to synchronize picture taking operations with the firing of the gun. Most sites are operated by local personnel who have been trained by SIR.

During a typical night's operation, the gun is fired at one to two hour intervals, from sunset to sunrise. Photographs are taken by all sites during the time that the trail is visible. The film is then returned to Atlanta for processing and data reduction.

DATA REDUCTION

Several computer programs have been developed which make it possible to calculate upper atmosphere winds from measurements made directly on the photographs of the luminous trails.

Since the method used is basically three-dimensional triangulation using spherical trigonometry, it is necessary to know precisely the direction each camera was pointed during a given firing. The direction is determined by first taking accurate measurements of the locations of several star images on the film, and then computing the azimuth and elevation of the optical axis of the camera by means of a computer program. This computer program makes use of the celestial coordinates of some 6,000 stars which have been stored on magnetic tape.

Wind speeds and directions are then determined from the location of the trail in space at a succession of known times. The location is found, using either a point location program or a trail location program, or both, and depends on the physical shape of the chemical release cloud.

Point location method. If the chemical release exhibits discrete points (resulting either from turbulence or from the nature of the release mechanism) and these points can be identified on films from two or more islands, the point location program can be used to calculate the position of each point in longitude, latitude, and altitude above sea level.

These calculations are made from data taken at successive times. A wind program is then used to calculate both vertical and horizontal winds from the motion of these points as a function of time.

Trail location method. Most of the chemical releases produce a smooth trail having few, if any, identifiable points. In such cases, film coordinates of a large number of incremental points along the film image of the trail are fed into the computer from data from two or more sites. The trail location program attempts to triangulate each point from one site with many points from another site, finally choosing points from both sites whose optical paths from camera into space form the closest spatial intersection. After doing many hundreds of such calculations, the computer is able to construct coordinates for a mathematical curve in the shape of the trail in space. Then, as with the point location program, winds can be determined from the motion of the curve with time. Here, however, it must be assumed that vertical winds are essentially zero. This assumption is borne out by pervious studies which have shown vertical winds in this altitude region to be of the order of a few meters per second compared to horizontal winds ranging up to 150 meters per second.

Corrections for variables such as atmospheric refraction, rotation of camera about optical axis, and camera focal length, are incorporated into the programs to maintain high accuracy. Focal length and camera rotation are, in fact, calculated from measurements of the positions of star images on the films.

INTERPRETATION OF DATA

Following the "Table of Trail Information", horizontal wind velocities are presented in tabular form and in plots of wind speed, direction, and components.

Winds were calculated at altitude intervals of one kilometer. Points on the various plots show the actual computed result, as listed in the table preceding the plot. A curve has been fitted to each set of points to aid in detecting wind patterns and to indicate reliability of the plotted results. Each curve has been drawn with a knowledge of intermediate results leading to the wind calculations and of the consistency of the winds as calculated between each of the five or more time intervals used. In cases where point-to-point curve fitting was not thought to reflect actual variations in wind speed, direction, or components, a more appropriate smooth curve has been drawn. Otherwise, the curves are fitted directly to the data points. Results of certain portions of the trails are at times less accurate than others due to the spatial orientation of those trail segments relative to the available photo graphic stations. Less accurate data can also result from photographs obscured by haze and clouds and from trails of short duration.

Wind speed plot. This plot shows the speed of the wind in meters per second as a function of height in kilometers above sea level.

Wind direction plot. The wind vector is considered to point in

the direction toward which the wind is moving. The direction plot shows the direction of this vector in degrees clockwise from north as seen from above. Thus, a wind direction toward the east would be 90 degrees.

Wind components plot. While plots of wind direction and speed do completely describe the wind vector, it has been found helpful in studying wind patterns to present the north-south (N-S) and east-west (E-W) velocity components of the vector. In the north-south plot, north is positive; south is negative. In the east-west plot, east is positive; west negative. Components are plotted in meters per second versus height in kilometers.

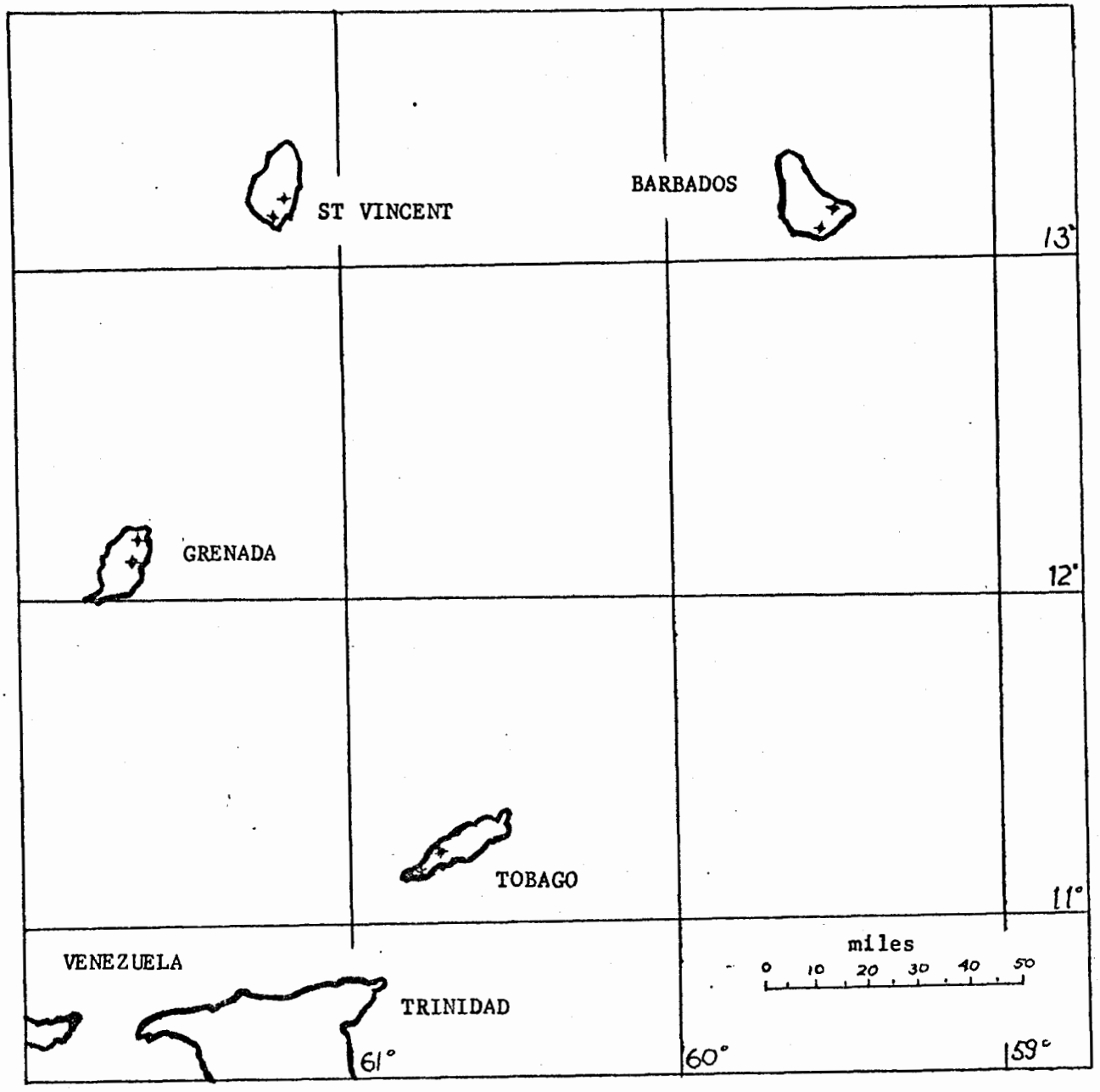
The wind direction and components described above are referenced to true north. In addition, components have been calculated relative to magnetic north for comparison with other ionospheric phenomena. These components are not plotted but are listed in the tabulations preceding each set of plots.

Throughout this report, where shorter notation was desirable, "Up" or "U" and "Down" or "D" have replaced uptrail and downtrail, respectively.

Ground Plot. This is a plot of the path of the probe with respect to latitude and longitude. Though the altitude of the probe is not plotted, the altitude in km. is marked along the curve so that the path of the vehicle can more easily be followed.

FIG. 1

Location of S.I.R. photographic stations

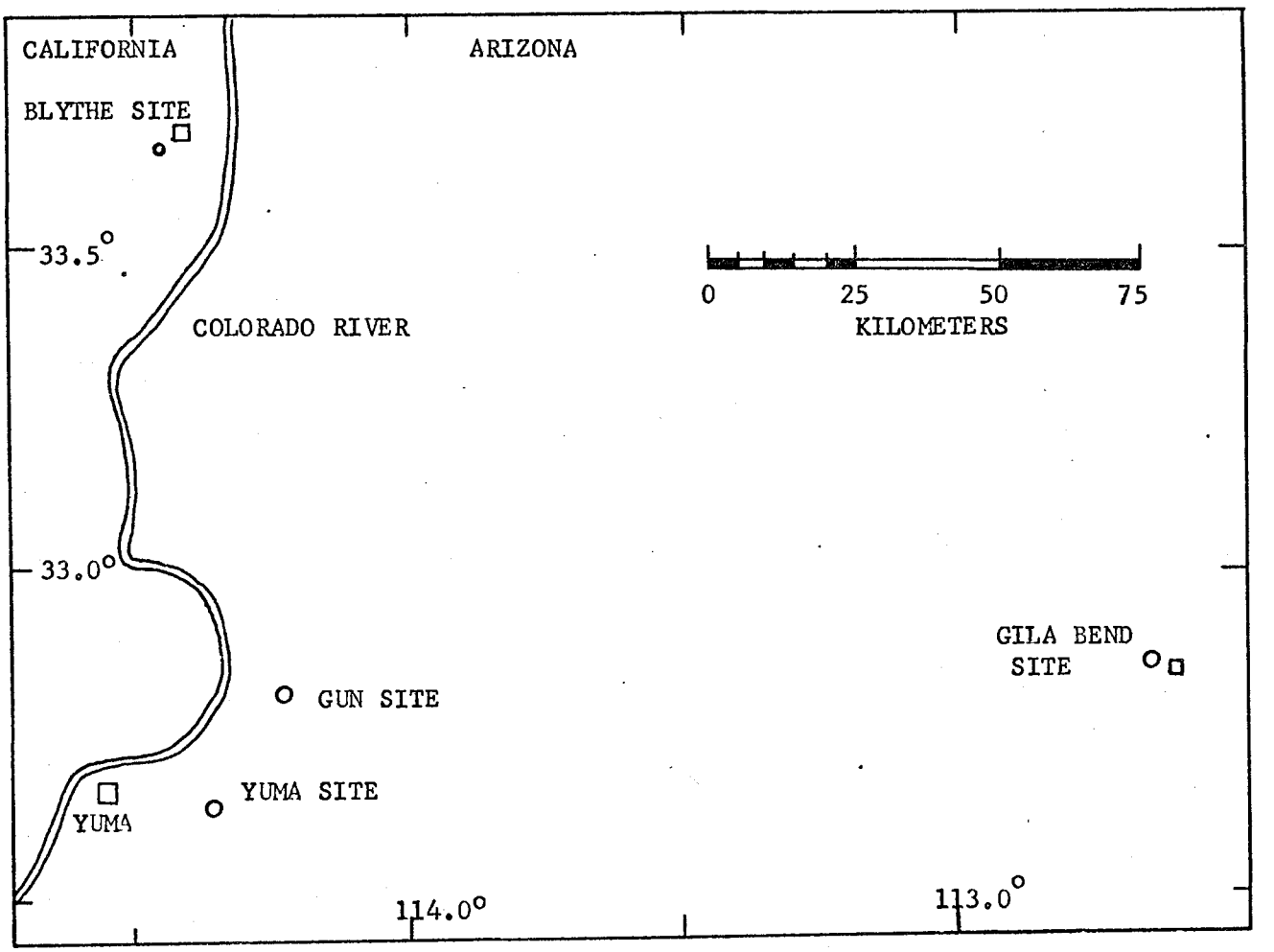


Two stations are located on each of the four islands, as shown. While only one station on each of any two islands is sufficient for determination of winds by triangulation, several stations were found necessary because of prevalent cloud conditions in the area. Accuracy of the data reduction is also increased by use of films from more than two islands.

FIGURE 2

LOCATION OF SIR PHOTOGRAPHIC STATIONS

H.A.R.P. - YUMA



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22. Delete "(accepted for June issue)"
Add "pp. 640-644, June 1968."

B. BRL HARP Reports

Add:
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1. Add "(AD834218)"

15. Add "(AD666746)"

16. Add "(AD666744)"

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Omit footnote which follows #30.

34. Add "(AD667917)"

Add:
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TABLE OF TRAIL INFORMATION

TRAIL NO.	TRAIL NAME	DATE	TIME	ALTITUDES (KM)
B-67	CAIRO	21 JUNE 1967	22:47:00AST	89-107
B-68	DURBAN	22 JUNE 1967	19:51:00AST	95-110
Y-26	38	12 JUNE 1967	20:14:04MST	117-136

TABULATIONS AND PLOTS

THREE TMA TRAILS 21-22 JUNE, AND 12 JUNE 1967

NOTE: The wind vector as given in this report is considered to point in the direction toward which the wind is blowing (that is, a west wind is toward the west). Most meteorologists are accustomed to a 180° difference, (that is, a west wind is from the west).

TRAIL NO. B67 CAIRO

BARBADOS 21 JUNE 1967 22-47-00 AST

UP TRAIL

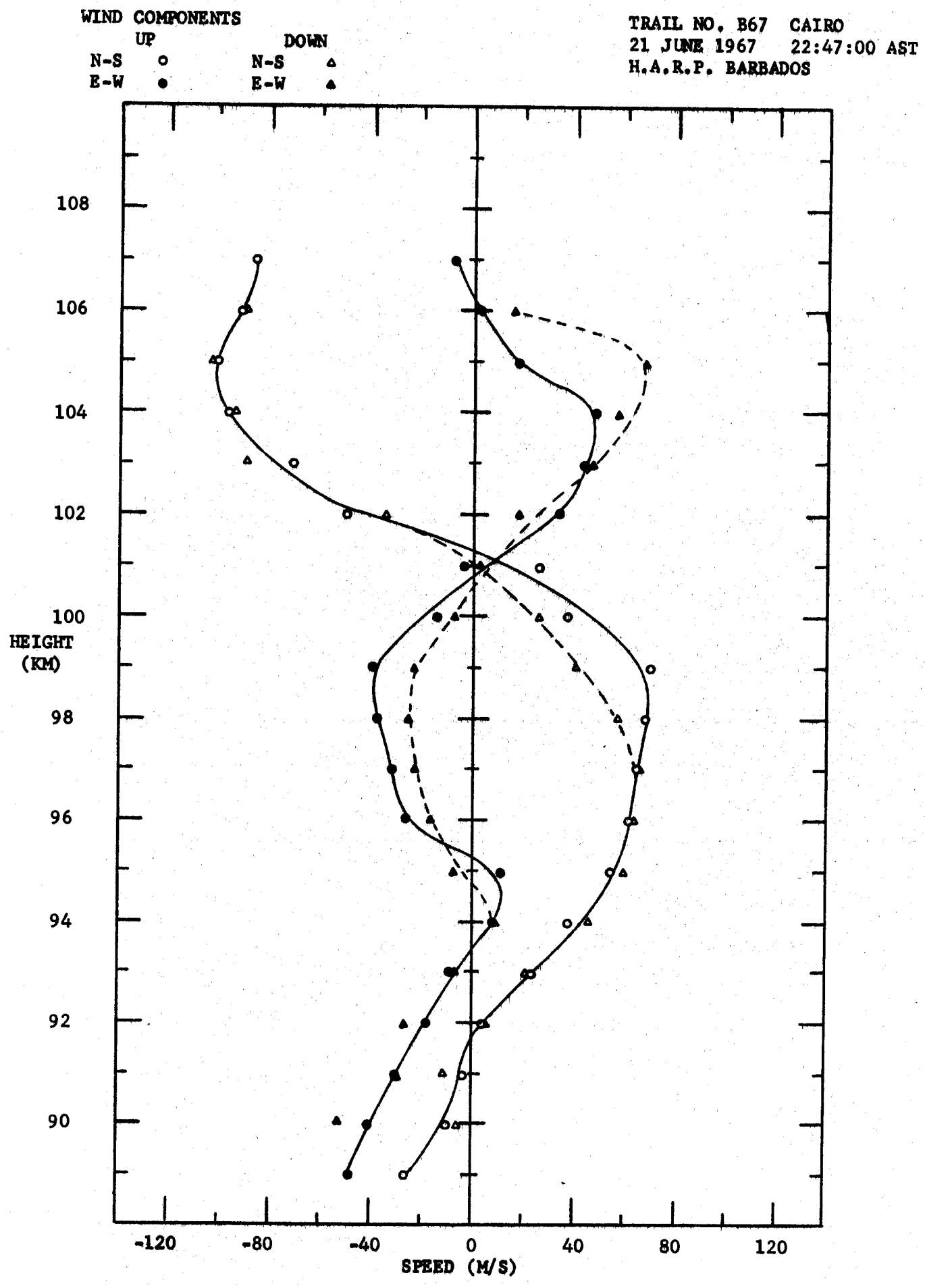
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) GEOGRAPHIC N-S	GEOGRAPHIC E-W	MAGNETIC N-S	MAGNETIC E-W
89.0	241.5	53.7	-25.6	-47.2	-15.3	-51.5
90.0	256.4	41.6	-9.8	-40.4	-1.3	-41.6
91.0	264.2	30.0	-3.0	-29.9	3.2	-29.9
92.0	285.1	17.2	4.5	-16.7	7.8	-15.4
93.0	339.5	25.8	24.2	-9.0	25.5	-3.8
94.0	13.3	39.1	38.1	9.0	35.4	16.7
95.0	12.5	58.1	56.7	12.5	52.9	23.9
96.0	337.0	67.5	62.2	-26.3	66.3	-12.9
97.0	334.3	72.3	65.1	-31.4	70.2	-17.3
98.0	331.0	78.4	68.5	-38.0	74.9	-23.1
99.0	330.9	80.2	70.1	-39.0	76.6	-23.7
100.0	339.9	39.6	37.2	-13.6	39.2	-5.6
101.0	352.6	26.4	26.2	-3.4	26.3	2.1
102.0	145.5	60.2	-49.6	34.1	-55.6	23.1
103.0	146.1	86.3	-71.6	48.1	-80.0	32.3
104.0	153.5	108.1	-96.7	48.3	-104.6	27.3
105.0	170.0	102.1	-100.6	17.8	-102.1	-3.3
106.0	178.5	91.0	-91.0	2.4	-89.5	-16.4
107.0	184.7	85.6	-85.3	-7.0	-82.0	-24.4

TRAIL NO. B67 CAIRO

BARBADOS 21 JUNE 1967 22-47-00 AST

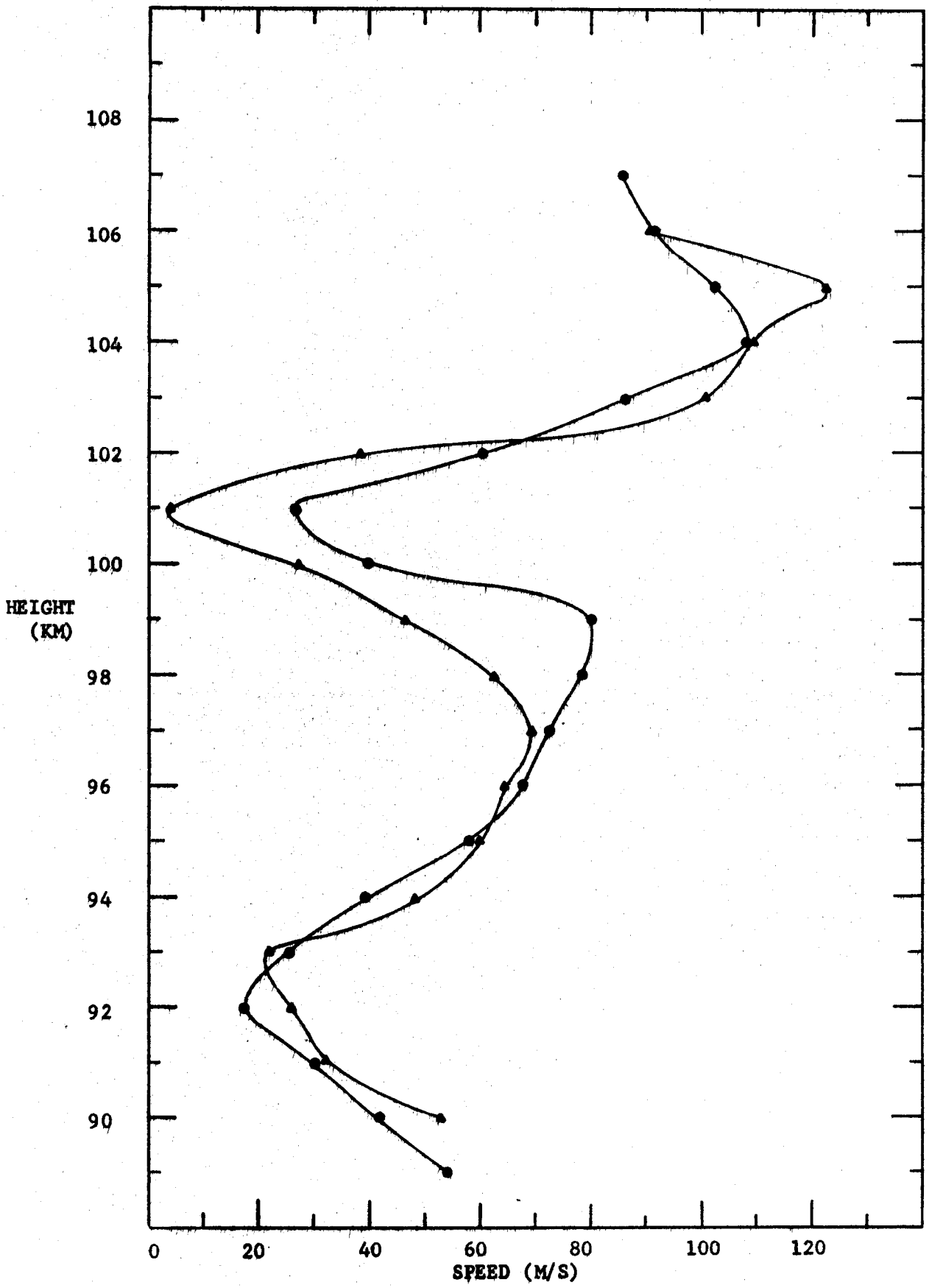
DOWN TRAIL

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) GEOGRAPHIC N-S	GEOGRAPHIC E-W	MAGNETIC N-S	MAGNETIC E-W
90.0	263.5	52.6	-5.9	-52.2	5.0	-52.3
91.0	250.5	31.5	-10.5	-29.7	-4.2	-31.2
92.0	279.4	26.0	4.3	-25.7	9.5	-24.3
93.0	343.0	21.9	20.9	-6.4	21.8	-2.0
94.0	10.8	48.1	47.3	9.0	44.4	18.6
95.0	353.7	59.9	59.5	-6.6	59.6	5.8
96.0	345.6	64.3	62.3	-16.0	64.3	-2.8
97.0	341.1	69.0	65.3	-22.3	68.5	-8.4
98.0	336.1	62.5	57.2	-25.3	61.2	-13.0
99.0	329.7	46.3	40.0	-23.3	43.9	-14.6
100.0	343.1	27.2	26.0	-7.9	27.1	-2.4
101.0	36.9	4.0	3.2	2.4	2.6	3.0
102.0	152.7	38.3	-34.1	17.6	-37.0	10.2
103.0	152.3	100.6	-89.1	46.8	-96.8	27.4
104.0	148.9	108.9	-93.2	56.3	-102.8	35.9
105.0	146.8	122.7	-102.7	67.1	-114.3	44.5
106.0	170.1	90.9	-89.5	15.6	-90.8	-3.2


WIND COMPONENTS
UP
DOWN
N-S
E-W
N-S
E-W
TRAIL NO. B67 CAIRO
21 JUNE 1967 22:47:00 AST
H.A.R.P. BARBADOS
108
106
104
102
100
98
96
94
92
90
HEIGHT (KM)
-120
-80
-40
0
40
80
120
SPEED (M/S)

WIND SPEED
UPTRAIL ●
DOWNTRAIL ▲

TRAIL NO. B67 CAIRO
21 JUNE 1967 22:47:00 AST
H.A.R.P. BARBADOS

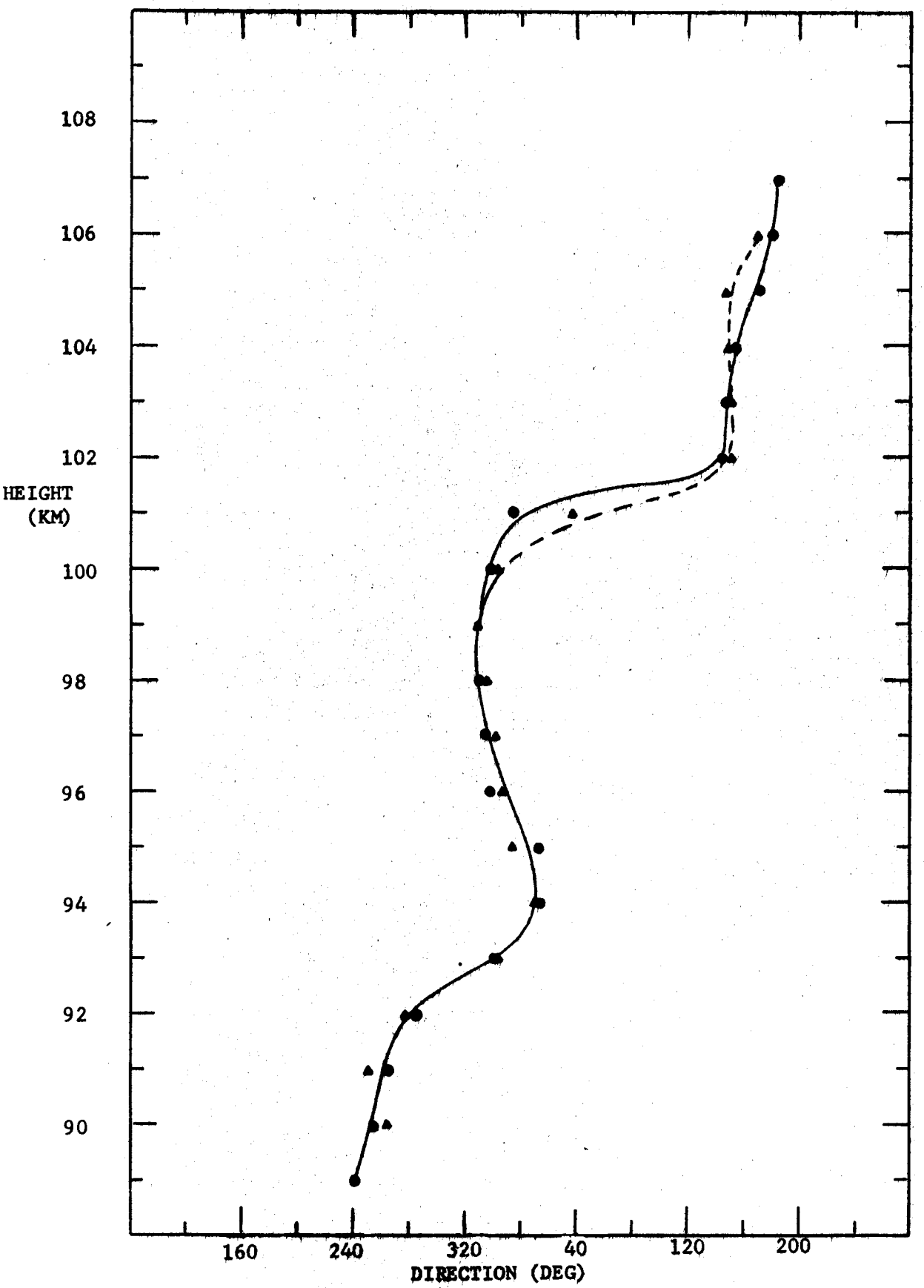


WIND DIRECTION

UPTRAIL ●

DOWNTRAIL ▲

TRAIL NO. B67 CAIRO
21 JUNE 1967 22:47:00 AST
H.A.R.P. BARBADOS



TRAIL NO. B68 DURBAN

BARBADOS 22 JUNE 1967 19-51-00 AST

UP TRAIL

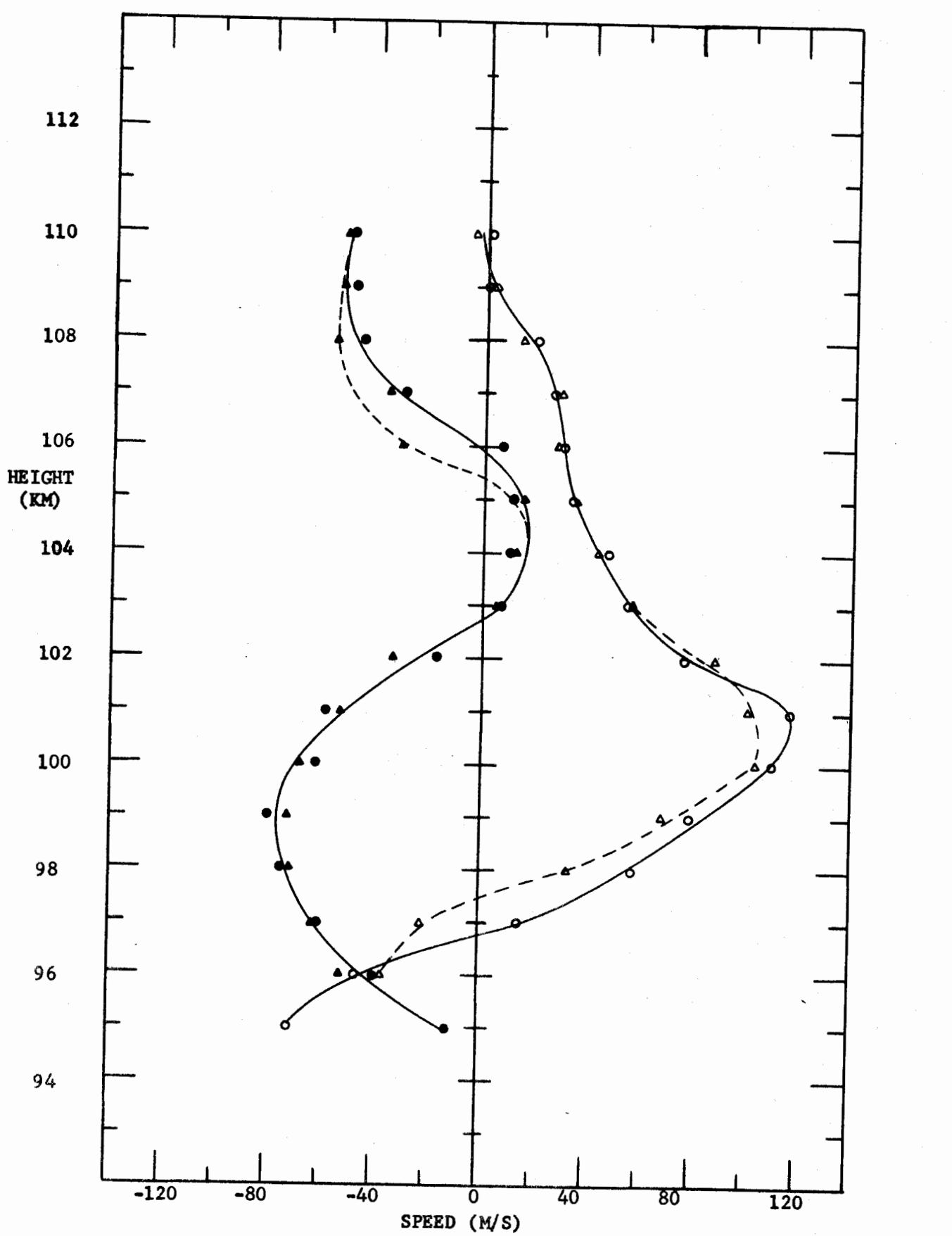
ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) GEOGRAPHIC N-S	GEOGRAPHIC E-W	MAGNETIC N-S	MAGNETIC E-W
95.0	189.3	72.0	-71.1	-11.6	-67.2	-26.0
96.0	220.1	60.0	-45.9	-38.6	-37.0	-47.2
97.0	283.8	62.1	14.8	-60.3	26.9	-56.0
98.0	307.7	94.4	57.7	-74.7	71.9	-61.2
99.0	318.6	105.6	79.2	-69.9	91.9	-52.1
100.0	330.7	126.7	110.5	-62.0	120.9	-37.9
101.0	332.5	124.0	117.0	-58.3	124.0	-46.6
102.0	347.5	78.7	76.8	-17.1	78.7	-0.9
103.0	7.8	55.3	54.8	7.5	52.1	18.6
104.0	12.0	48.5	47.4	10.1	44.3	19.7
105.0	17.5	35.4	33.8	10.7	30.9	17.4
106.0	13.1	30.7	29.9	6.9	27.8	12.9
107.0	311.5	40.0	26.5	-30.0	32.1	-23.9
108.0	292.6	49.6	19.1	-45.8	28.1	-40.9
109.0	270.8	49.1	0.7	-49.1	10.8	-47.9
110.0	272.1	50.1	1.8	-50.1	12.1	-48.7

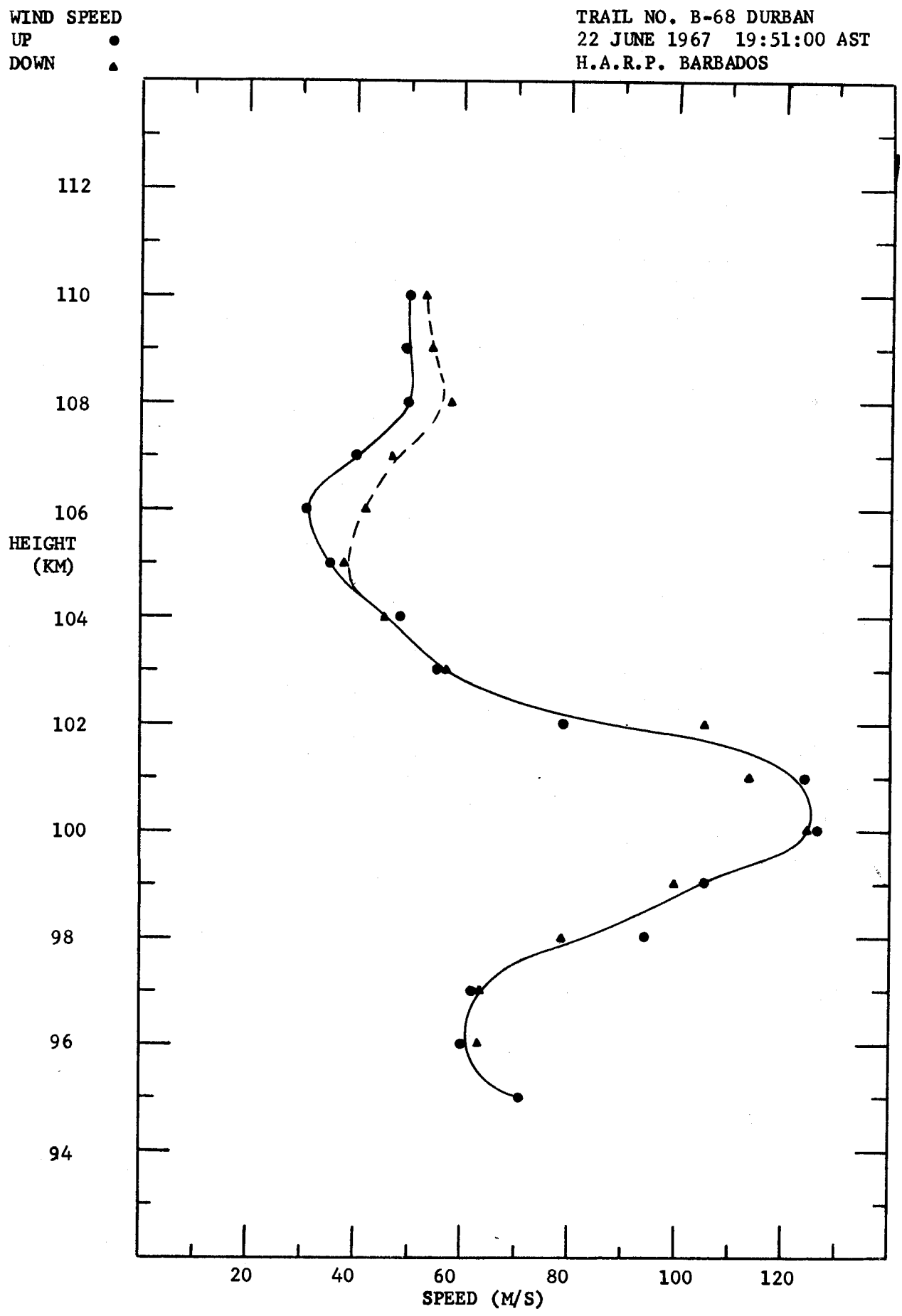
TRAIL NO. B68 DURBAN

BARBADOS 22 JUNE 1967 19-51-00 AST

DOWN TRAIL

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) GEOGRAPHIC N-S	GEOGRAPHIC E-W	MAGNETIC N-S	MAGNETIC E-W
96.0	235.2	63.4	-36.2	-52.0	-24.7	-58.3
97.0	259.7	63.5	-11.3	-62.5	1.8	-63.5
98.0	295.3	78.7	33.6	-71.2	47.6	-62.7
99.0	313.8	99.7	69.0	-72.0	82.4	-56.2
100.0	327.0	124.4	104.4	-67.7	116.1	-44.7
101.0	332.7	113.8	101.1	-52.2	109.7	-30.2
102.0	339.2	95.2	89.0	-33.7	94.0	-14.6
103.0	5.5	57.1	56.8	5.5	54.4	17.1
104.0	16.0	45.6	43.8	12.6	40.3	21.4
105.0	24.0	37.9	34.6	15.4	30.7	22.2
106.0	312.4	41.7	28.1	-30.8	33.8	-24.3
107.0	309.0	46.5	29.3	-36.1	36.1	-29.3
108.0	284.3	57.8	14.3	-56.0	25.5	-51.8
109.0	274.4	53.7	4.2	-53.6	15.2	-51.6
110.0	265.1	52.6	-4.5	-52.4	6.4	-52.2


WIND COMPONENTS
NORTH-SOUTH
EAST-WEST
UP
DOWN
TRAIL NO. B-68 DURBAN
22 JUNE 1967 19:51:00 AST
H.A.R.P. BARBADOS
112
110
108
106
HEIGHT (KM)
104
102
100
98
96
94
-120
-80
-40
0
40
80
120
SPEED (M/S)

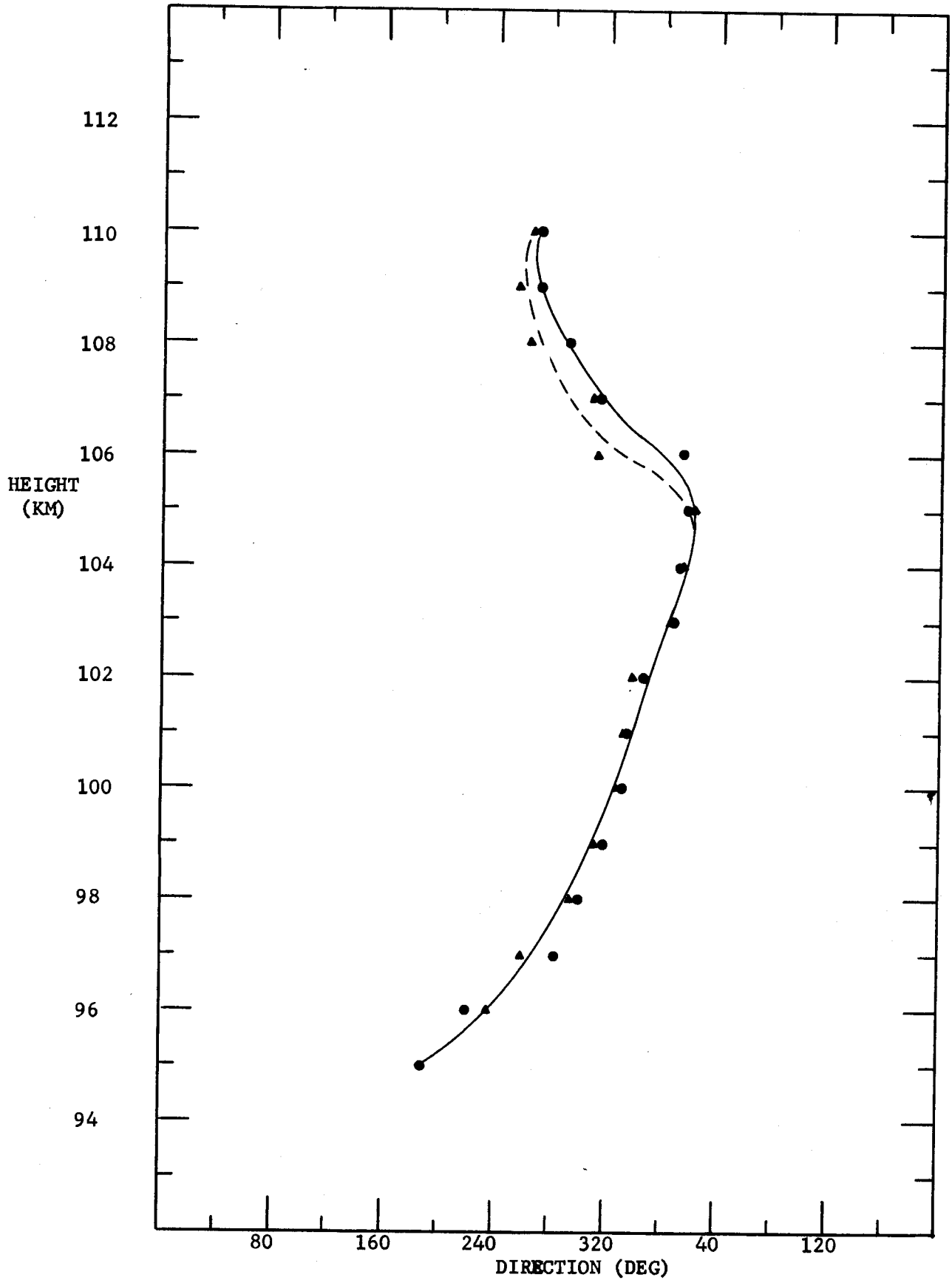

WIND SPEED
UP ●
DOWN ▲
TRAIL NO. B-68 DURBAN
22 JUNE 1967 19:51:00 AST
H.A.R.P. BARBADOS
112
110
108
106
HEIGHT (KM)
104
102
100
98
96
94
20
40
60
80
100
120
SPEED (M/S)

WIND DIRECTION

UP ●

DOWN ▲

TRAIL NO. B-68 DURBAN
22 JUNE 1967 19:51:00 AST
H.A.R.P. BARBADOS



TRAIL NO. Y-26

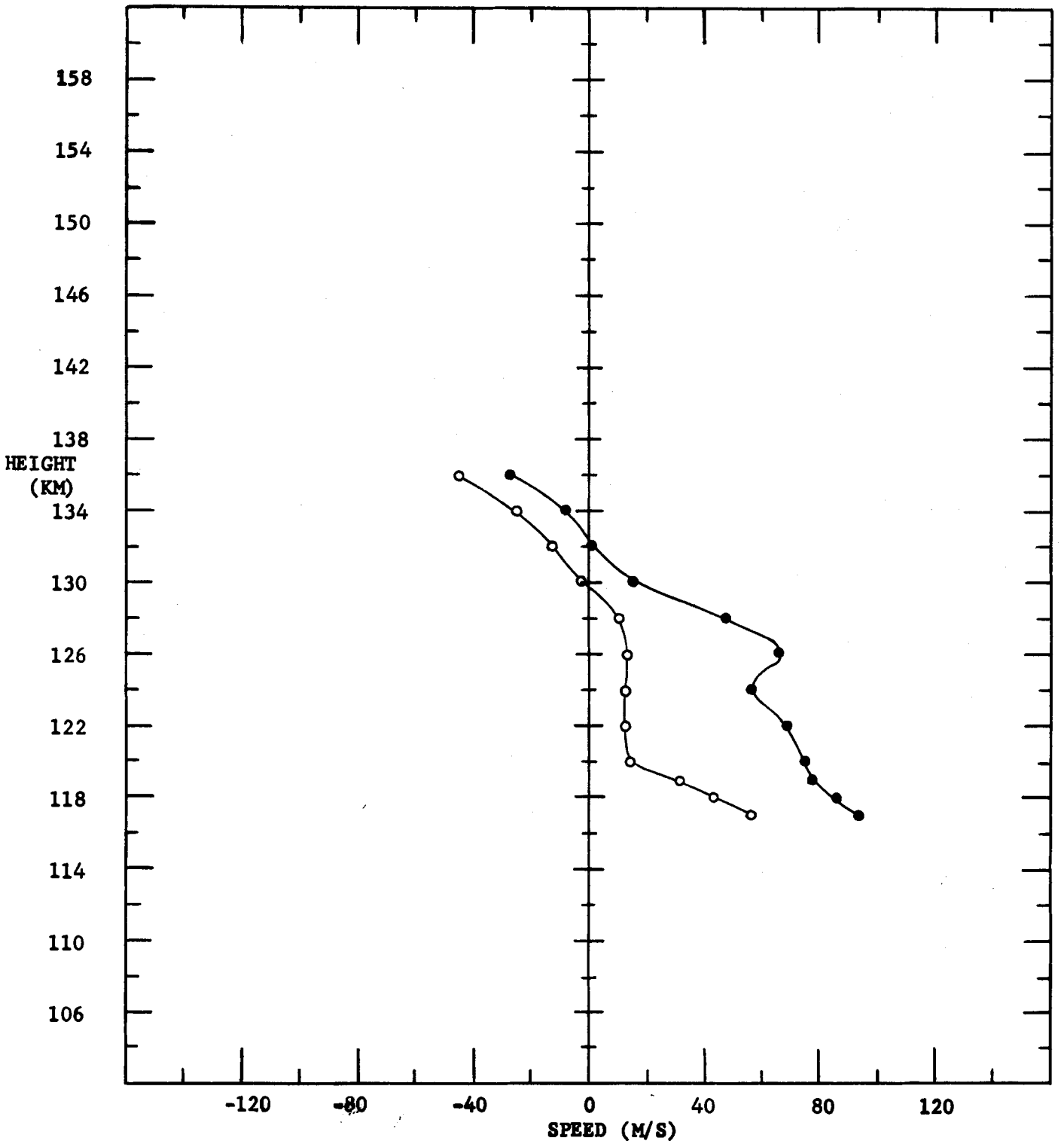
YUMA 12 JUNE 1967 20-14-04 MST

UP TRAIL

ALTITUDE (KM)	WIND HEADING (DEG)	WIND VELOCITY (M/S)	WIND COMPONENTS (M/S) GEOGRAPHIC N-S	GEOGRAPHIC E-W	MAGNETIC N-S	MAGNETIC E-W
117.0	59.3	112.8	57.6	97.0	79.8	79.7
118.0	63.0	96.3	43.7	85.8	63.6	72.3
119.3	68.1	83.7	31.2	77.6	49.5	67.4
120.0	78.9	76.1	14.7	74.7	32.8	68.7
122.0	78.8	70.2	13.6	68.9	30.3	63.4
124.0	77.1	57.2	12.8	55.8	26.2	50.9
126.0	77.9	66.9	14.0	65.4	29.8	59.9
128.0	76.7	48.9	11.2	47.6	22.6	43.3
130.0	97.5	15.6	2.0	15.5	5.8	14.5
132.0	175.1	12.4	12.3	1.0	12.2	-2.1
134.0	197.2	25.9	24.7	7.7	25.8	1.3
136.0	201.8	47.5	44.1	17.7	47.1	6.2

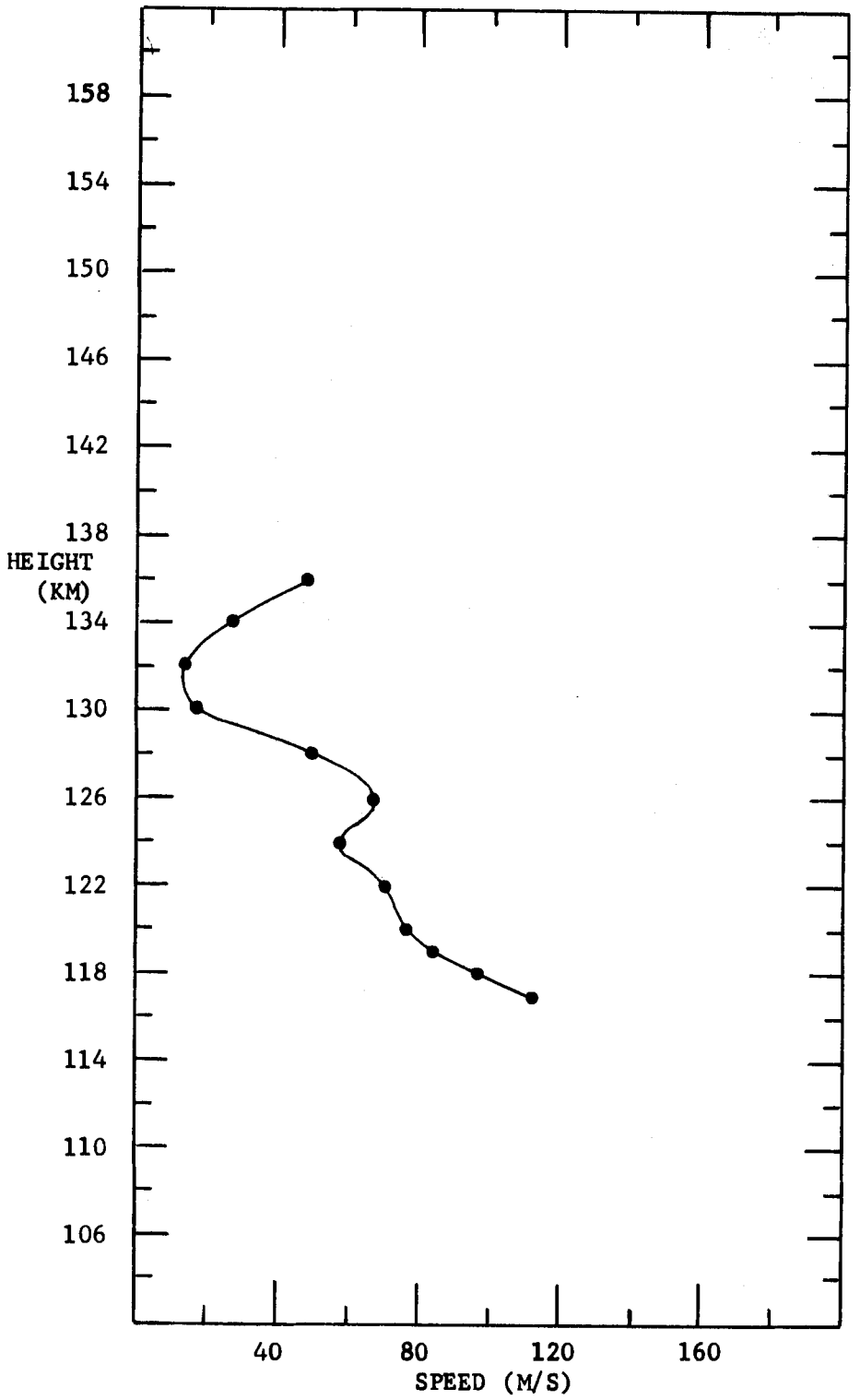
WIND COMPONENTS
UP
NORTH-SOUTH o
EAST-WEST ●

TRAIL NO. Y-26
12 JUNE 1967
20:14:04 MST
H.A.R.P. YUMA



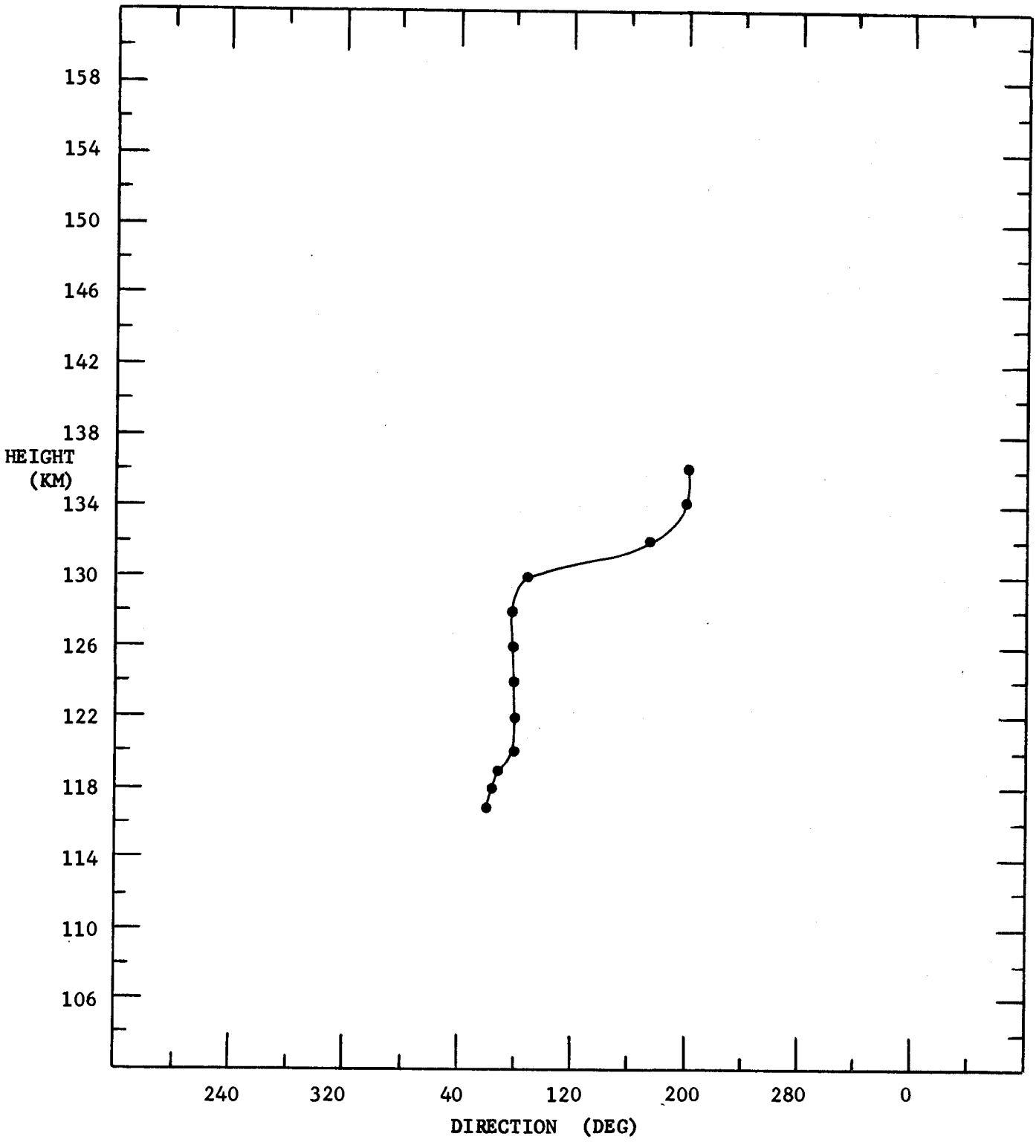
WIND SPEED
UP ●

TRAIL NO. Y-26
12 JUNE 1967
20:14:04 MST
H.A.R.P. YUMA



WIND DIRECTION
UP ●

TRAIL NO. Y-26
12 JUNE 1967
20:14:04 MST
H.A.R.P. YUMA



GROUND PLOTS

Barbados:

*Report	Trail No.	Name	Time
1	B-12	Elagabulus	288
2	B-19	Belair	278
3	B-31	Christ Church	338
	B-32	Dover	up 308 down 318
	B-33	Foul Bay	258
5	B-43	Inagua	283
	B-49	St. Thomas	263
8	B-51	Beta	U282, D292
	B-52	Gamma	352
	B-53	Delta	322
	B-55	Zeta	292
	B-57	Theta	262
9	B-59	Belfast	262
	B-61	Dublin	252
	B-63	Hollywood	U172, D252
	B-65	Limerick	252
10	B-67	Cairo	212
	B-68	Durban	342
Yuma:			
4	Y-4	McConnell	U252, D272
6	Y-13	Shot 20	252
	Y-15	Shot 23	262
	Y-22	Shot 31	222

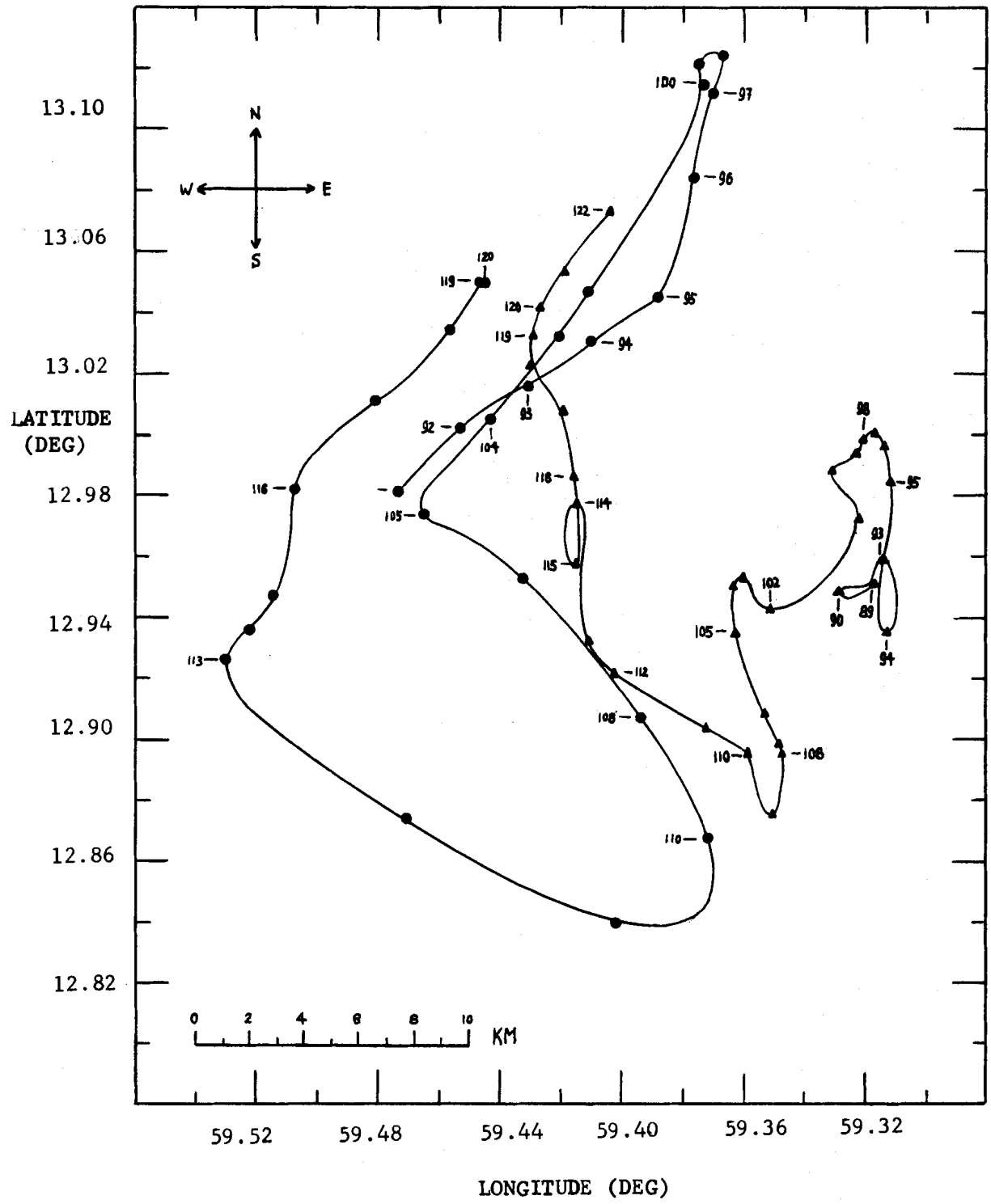
*This refers to the BRL contract report which contains the wind plots and tables.

GROUND PLOT
T + 288 SECONDS

H.A.R.P. BARBADOS
TRAIL NO. B-12
ELAGABULUS 4 JUNE 1965
01:34:56 A.S.T.

UPTRAIL ●

DOWNTRAIL ▲

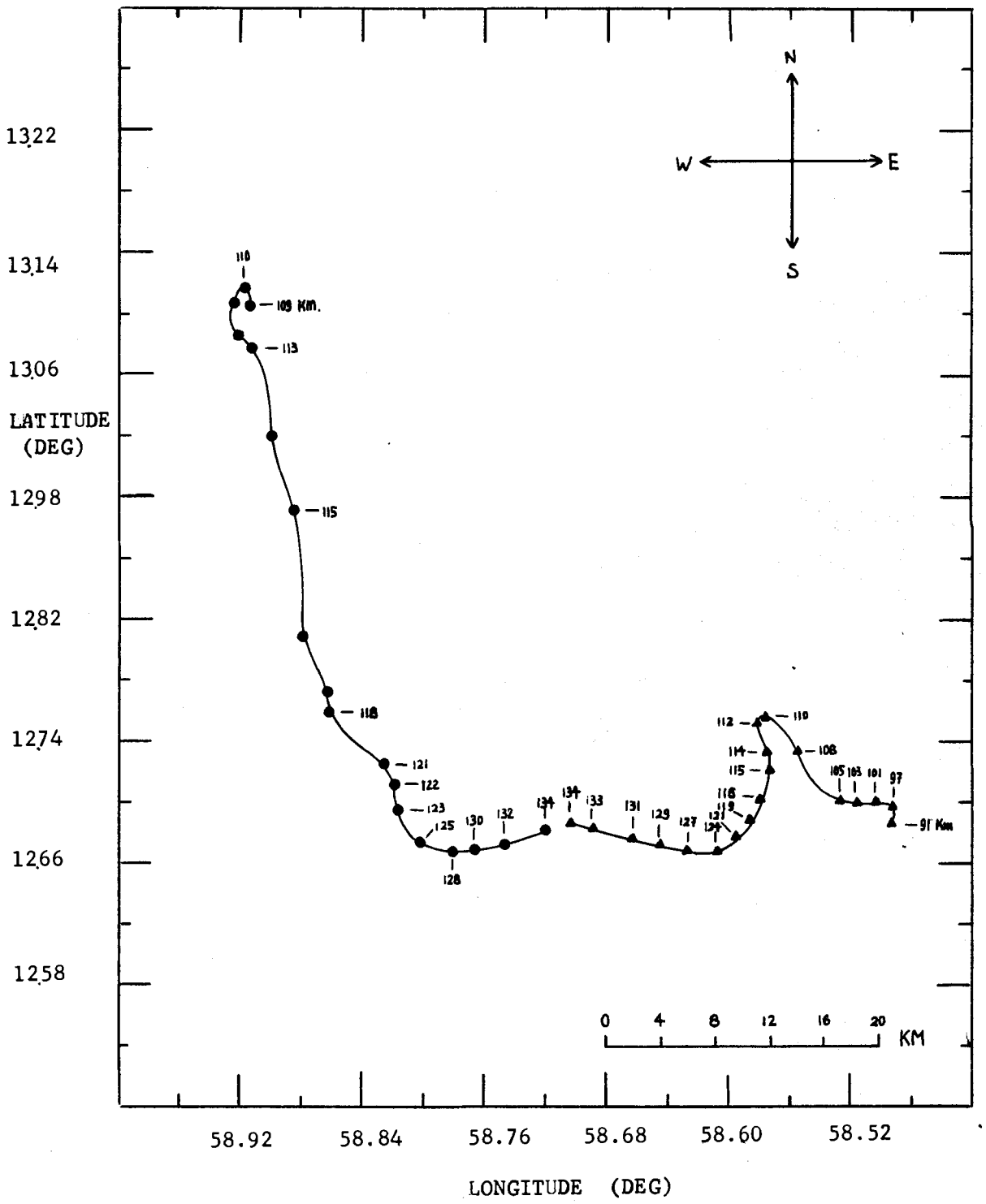


GROUND PLOT
T + 278

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-19 BELAIR
20 SEPTEMBER 1965
19:30:00 A.S.T.

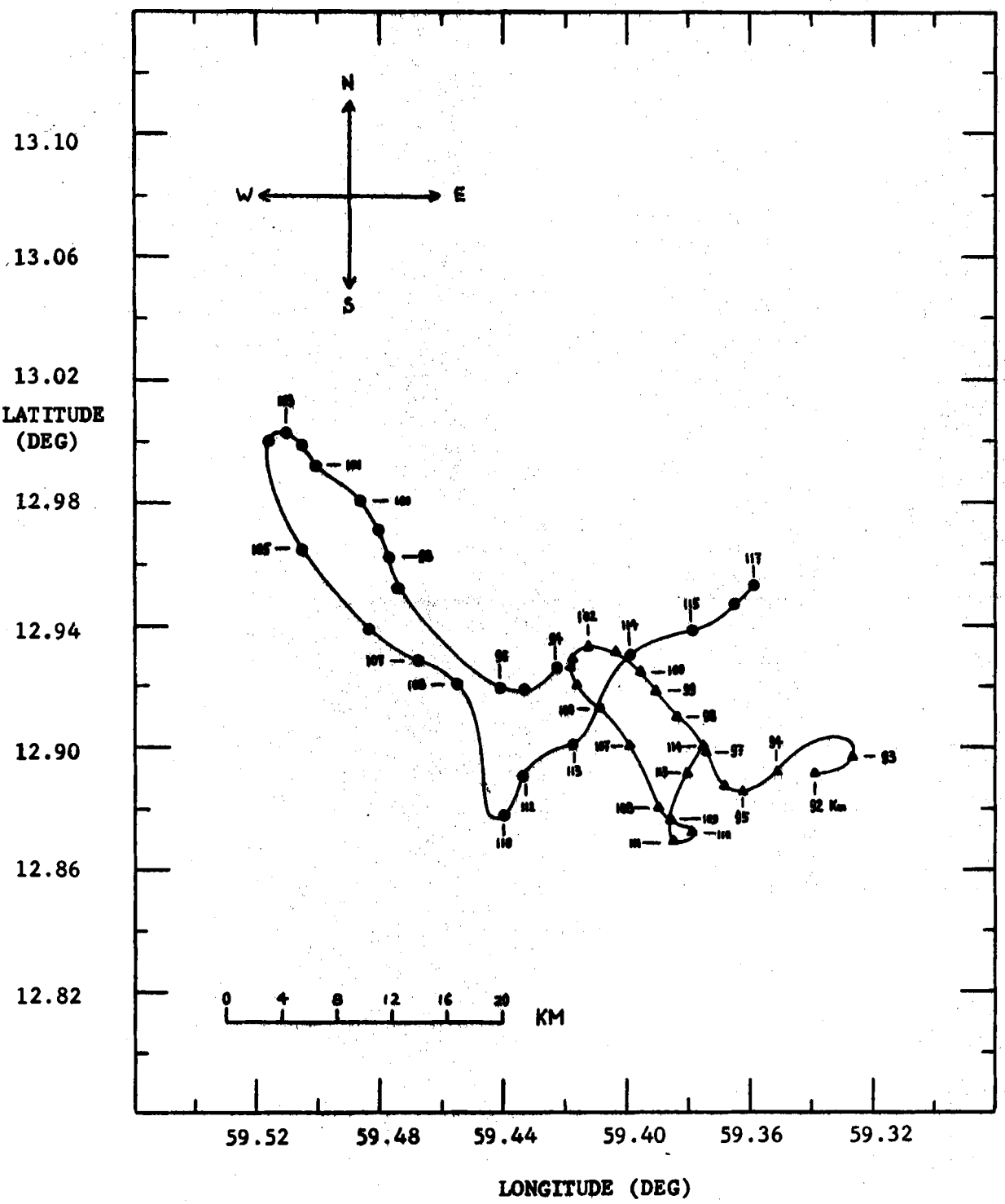


GROUND PLOT
T + 338 SECONDS

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-31 CHRISTCHURCH
17 NOVEMBER 1965
18:15:00 A.S.T.

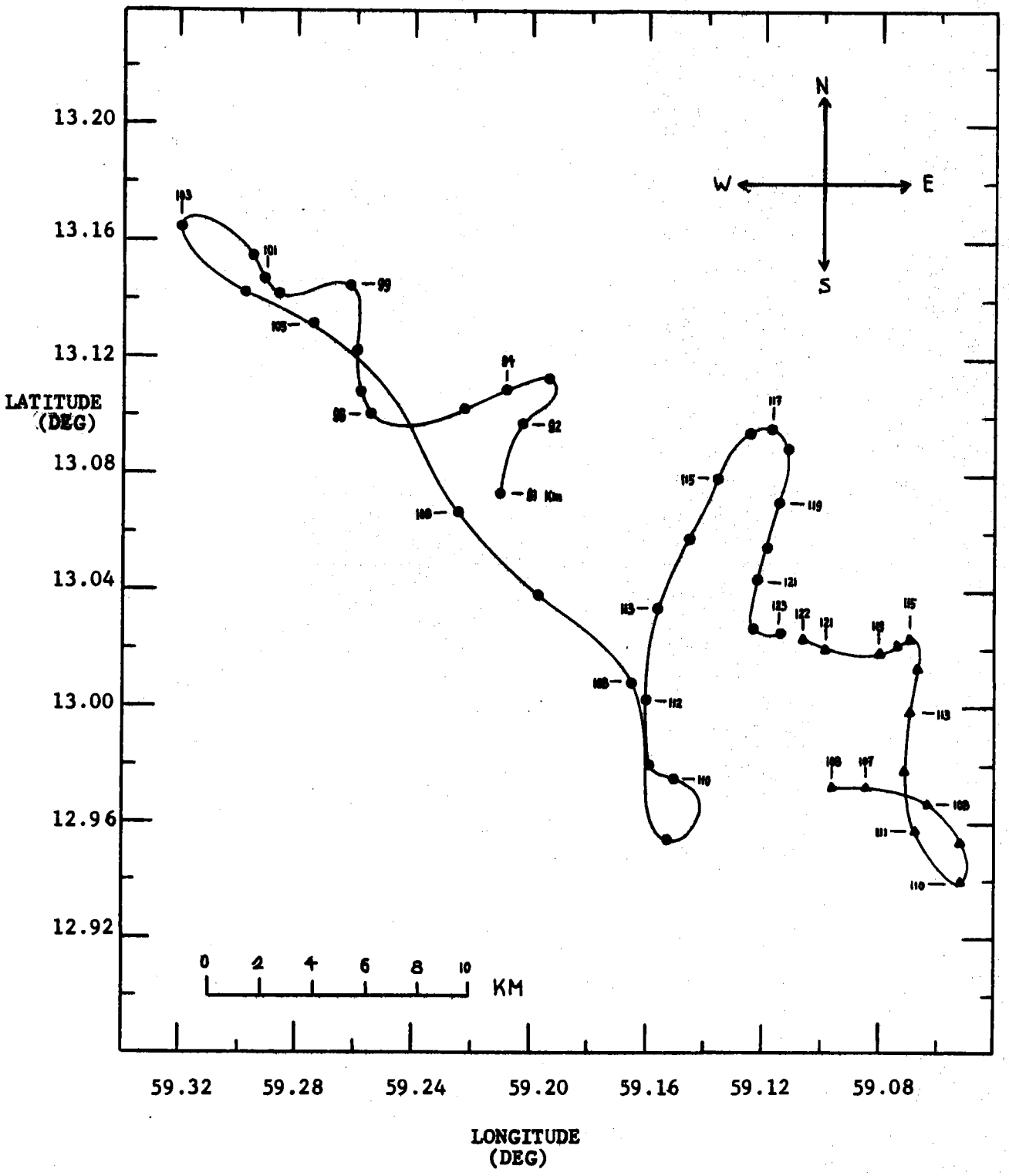


GROUND PLOT
UPTRAIL T +308 SECONDS
DOWNTRAIL T 318 SECONDS

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-32 DOVER
17 NOVEMBER 1965
19:34:00, A.S.T.

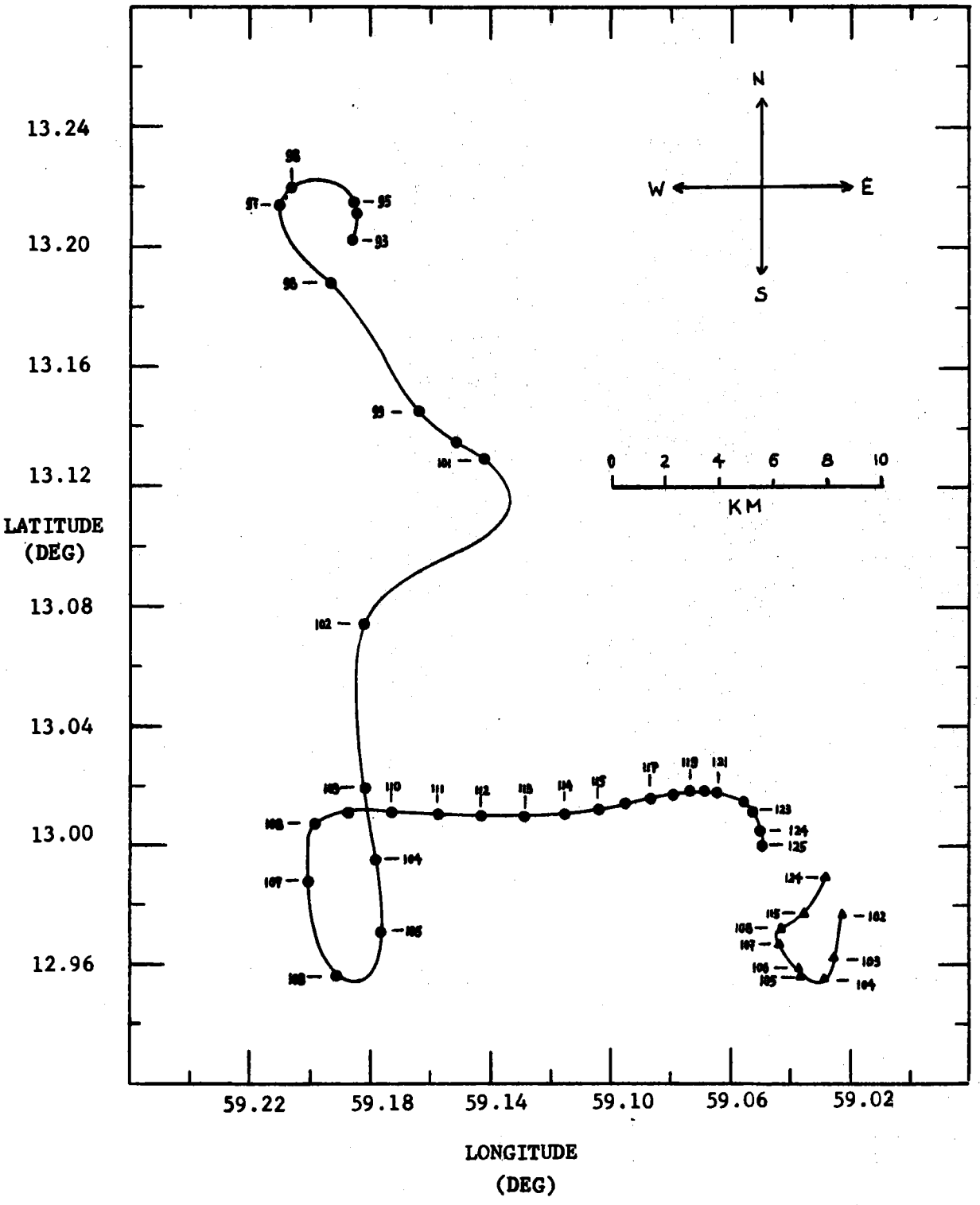


GROUND PLOT
T + 258 SECONDS

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-33 FOUL BAY
17 NOVEMBER 1965
23:15:00 A.S.T.

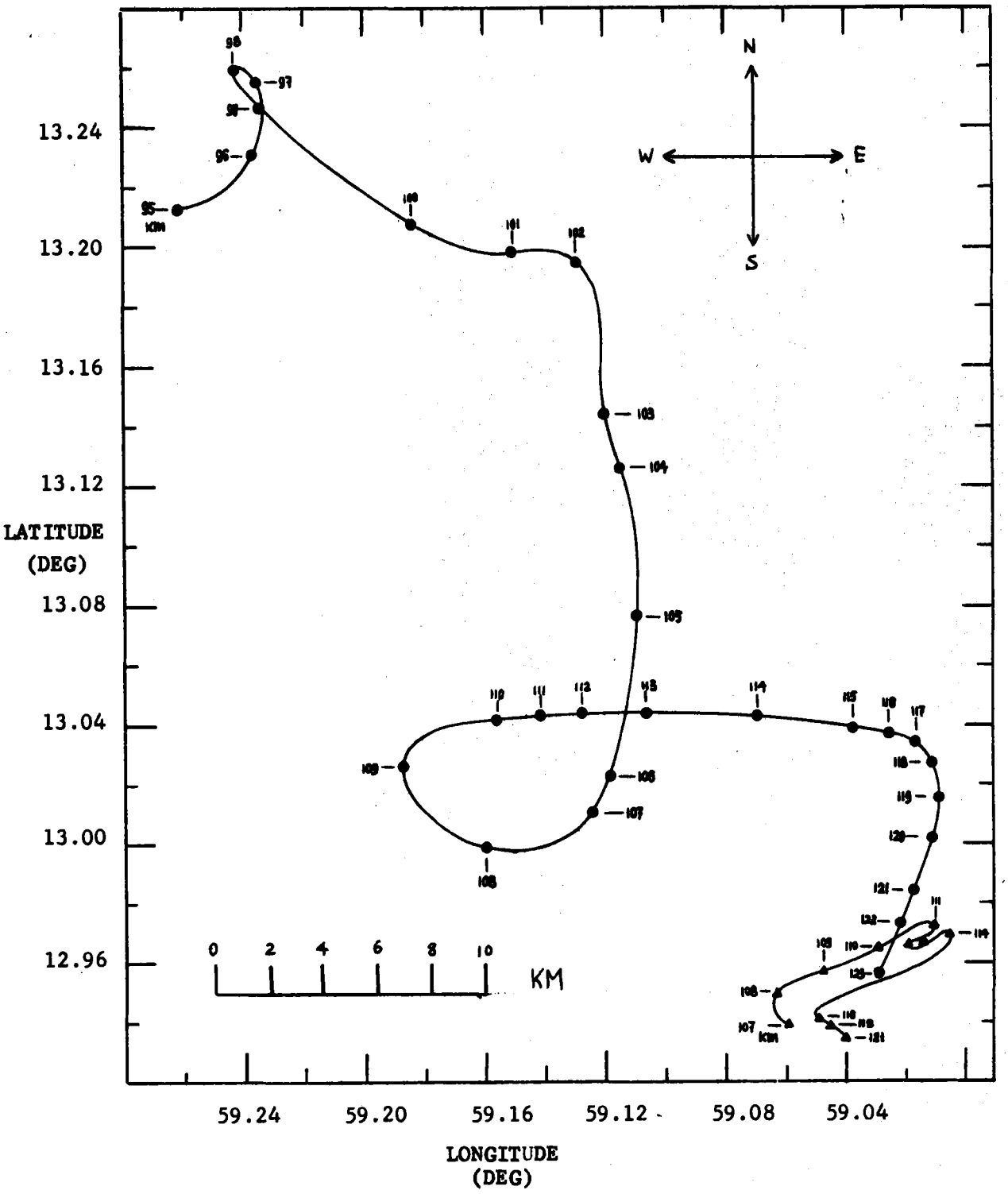


GROUND PLOT
UPTRAIL T + 283
DOWNTRAIL T + 293

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-43 INAUGUR
17 FEBRUARY 1966
21:03:00 A.S.T.

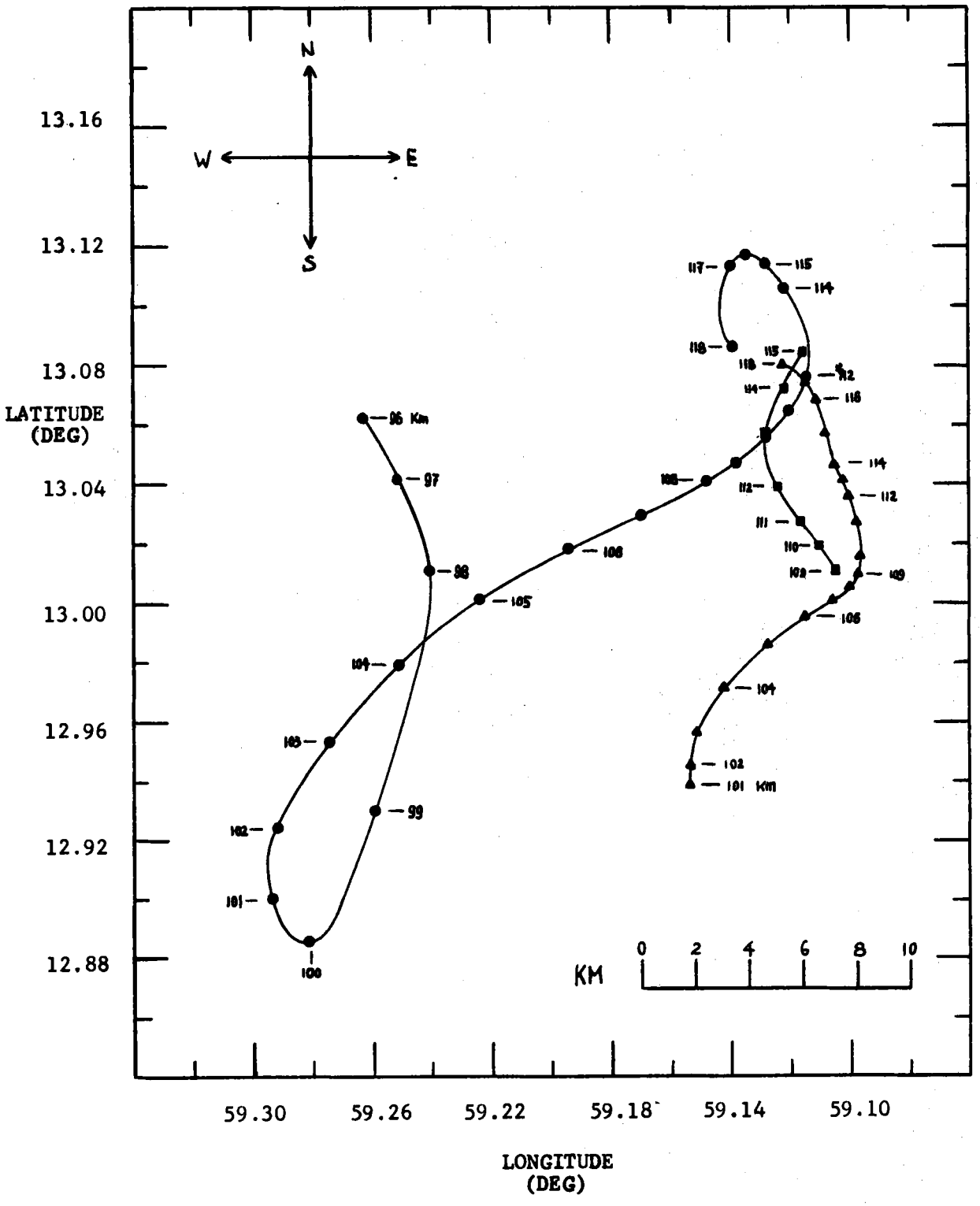


GROUND PLOT
T + 263
UPTRAIL ●

DOWNTRAIL ▲

TRAIL"A" DOWNTRAIL ■

H.A.R.P. BARBADOS
TRAIL NO. B-49 ST. THOMAS
24 FEBRUARY 1966
05:23:30 A.S.T.

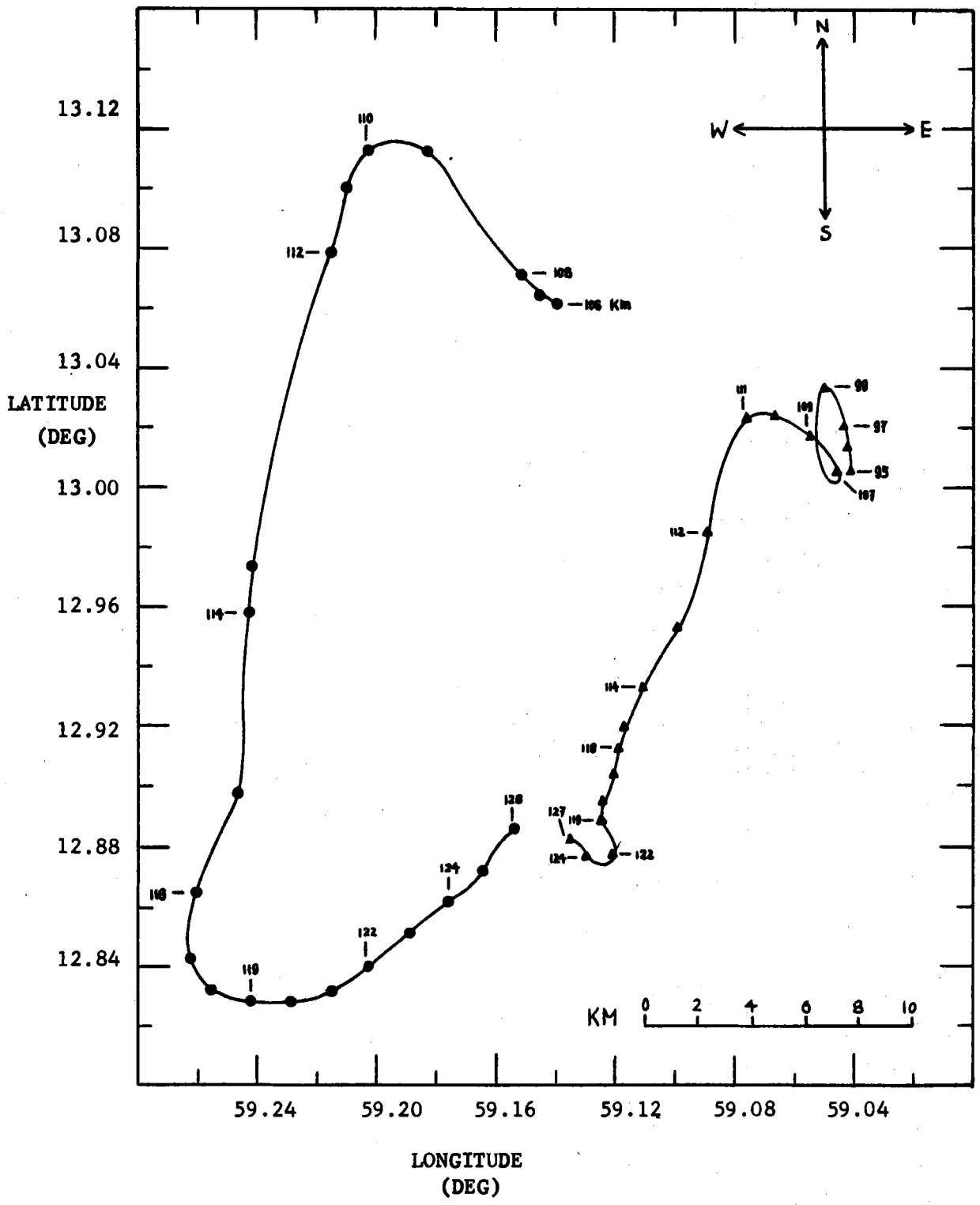


GROUND PLOT
UPTRAIL T + 282 SECONDS
DOWNTRAIL T + 292 SECONDS

H.A.R.P. BARBADOS
TRAIL NO. B-51 BETA
19 SEPTEMBER 1966
20:55:09 A.S.T.

UPTRAIL ●

DOWNTRAIL ▲



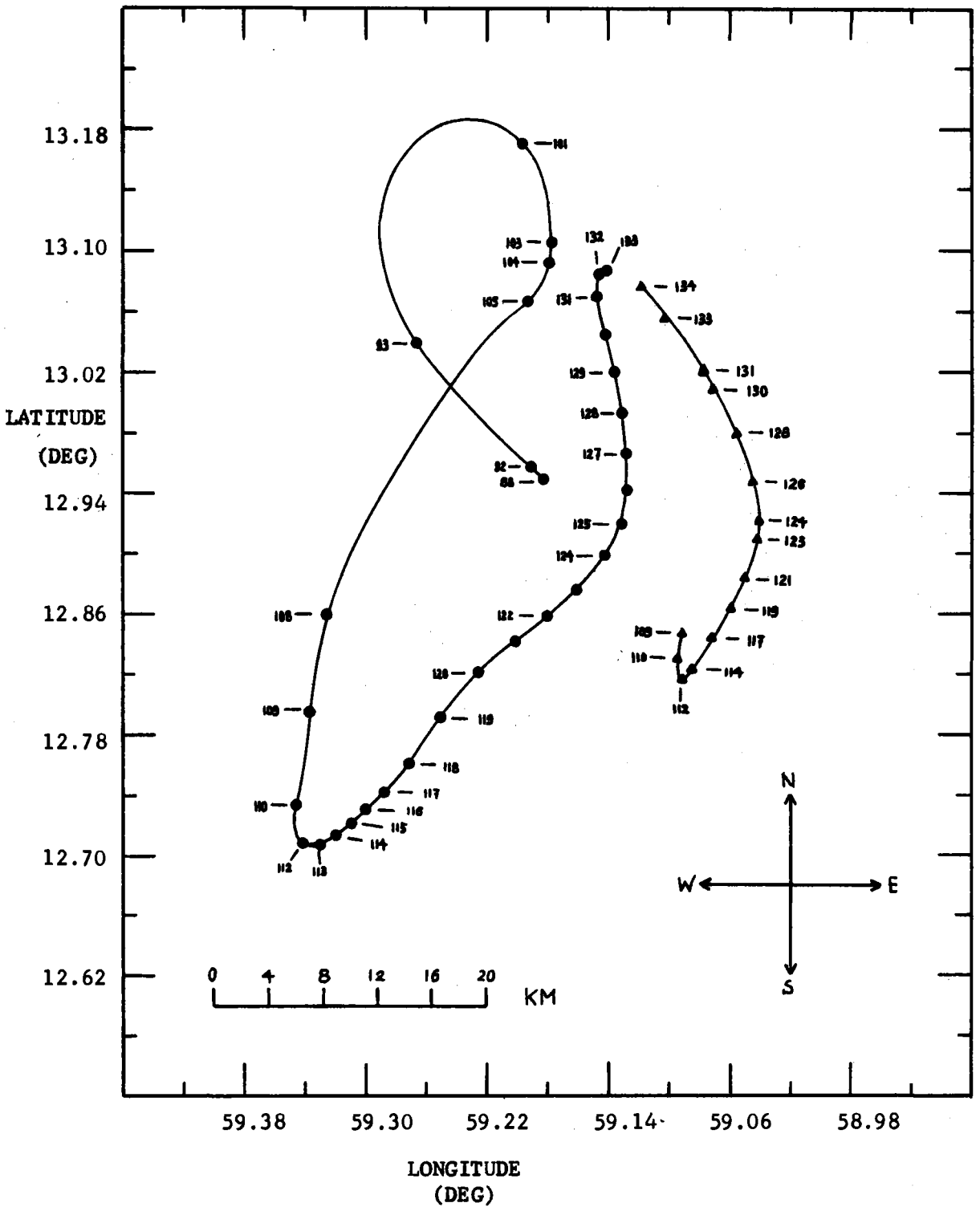
GROUND PLOT

T + 352

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-52 GAMMA
19 SEPTEMBER 1966
22:24:06 A.S.T.

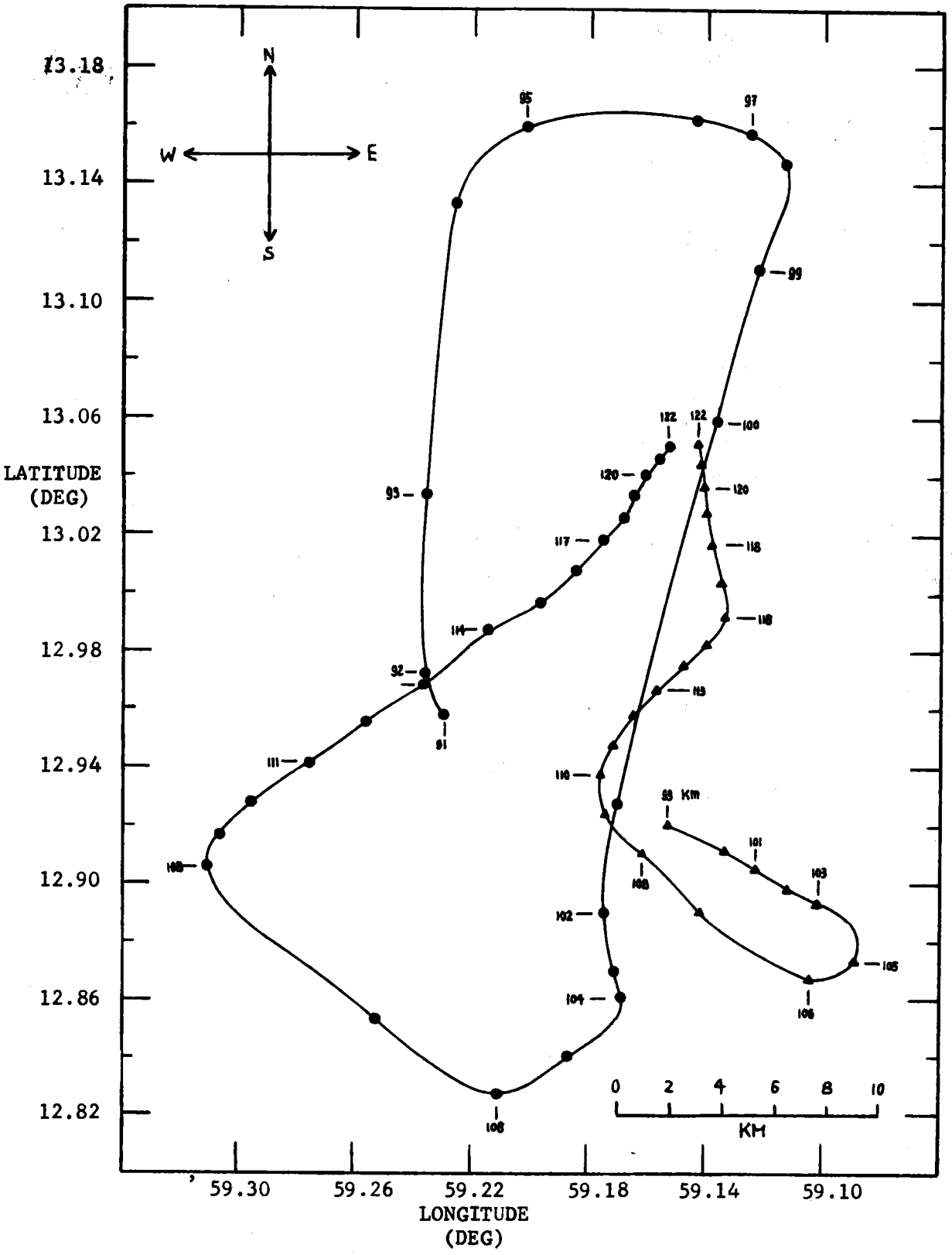


GROUND PLOT
T + 322

UPTRAIL ●

DOWNTRAIL ▲

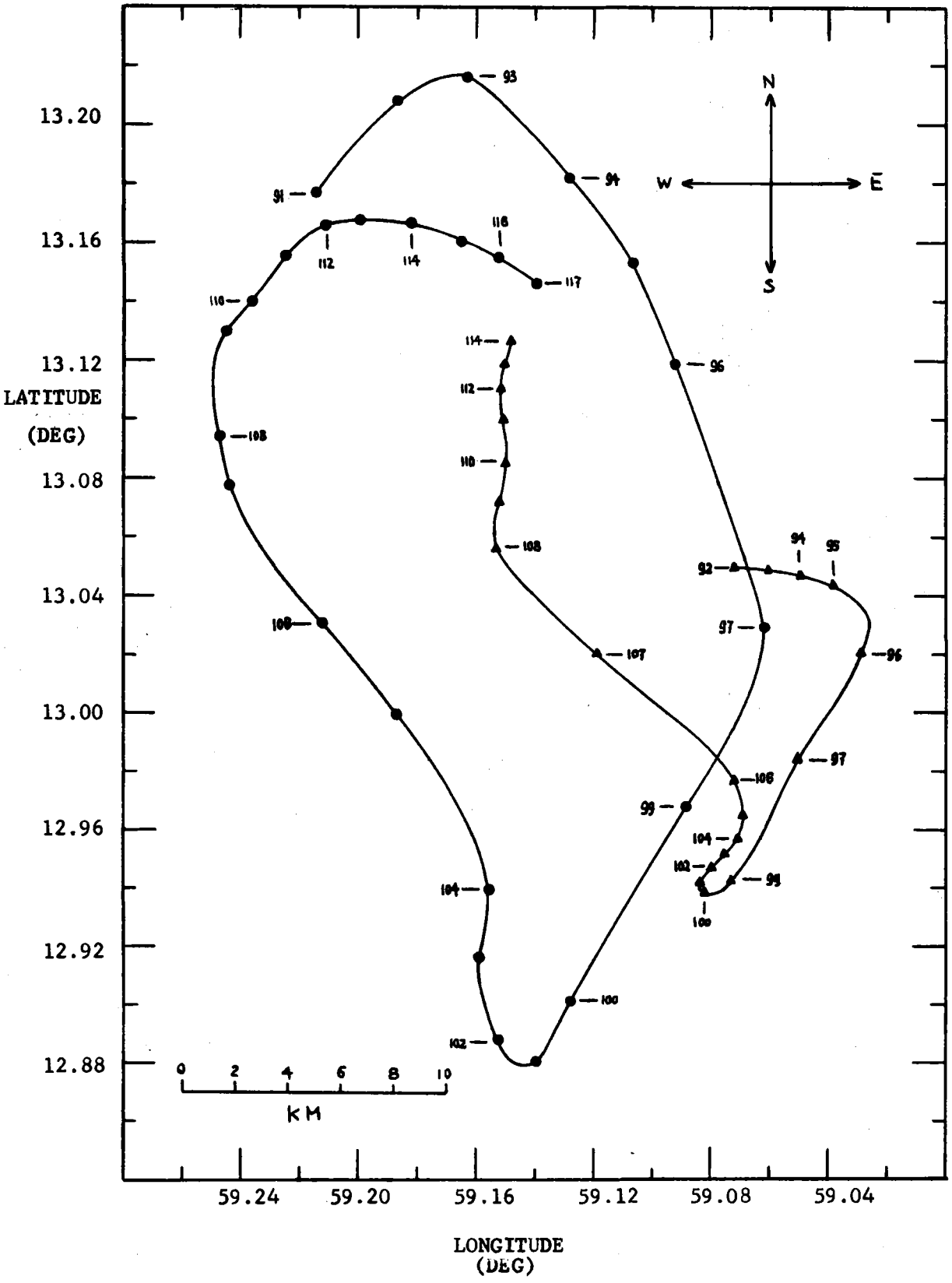
H.A.R.P. BARBADOS
TRAIL NO. B-53 DELTA
20 SEPTEMBER 1966
00:10:00 A.S.T.



GROUND PLOT
T + 292
UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-55 ZETA
20 SEPTEMBER 1966
02:24:00 A.S.T.

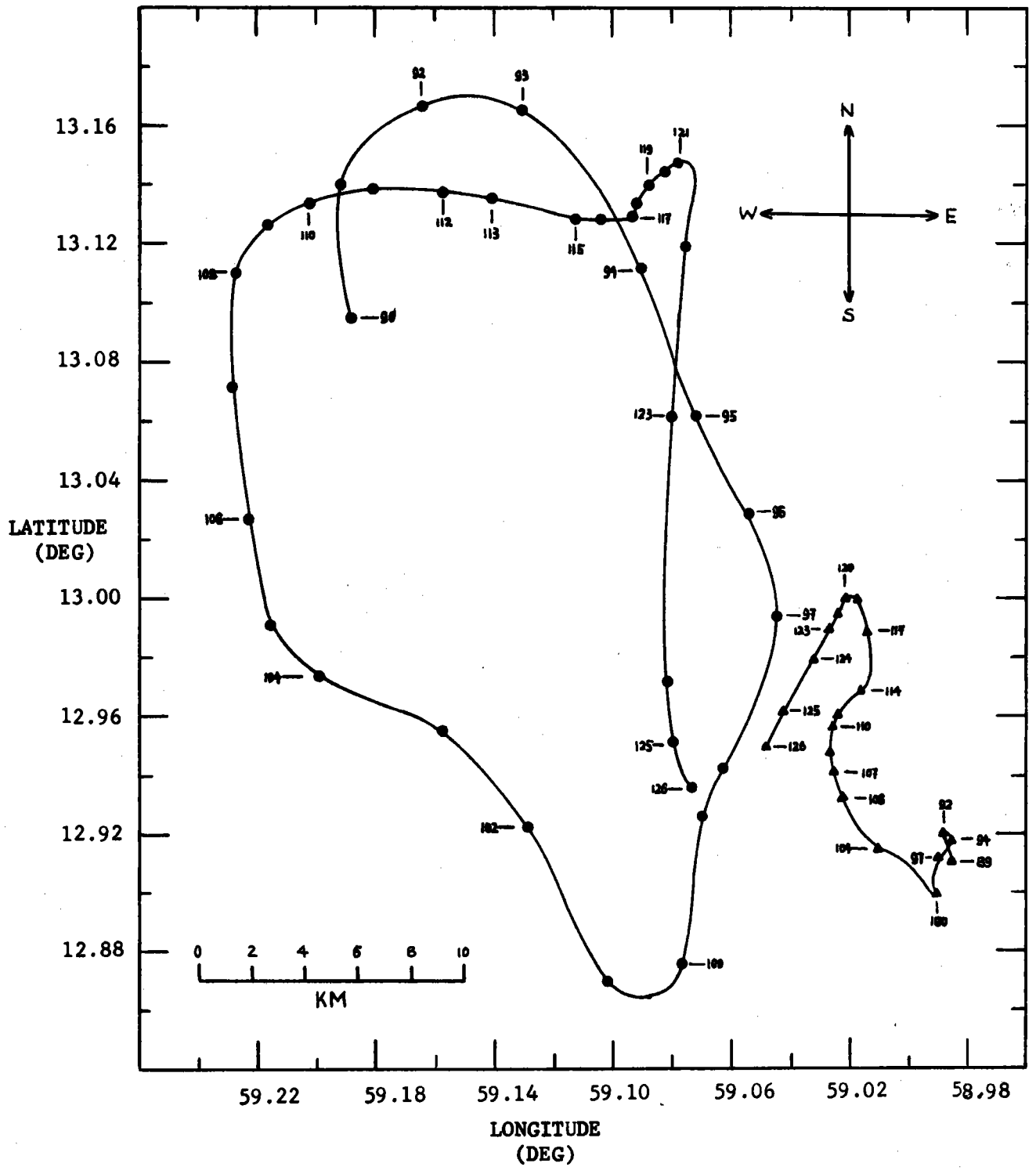


GROUND PLOT
T + 262

H.A.R.P. BARBADOS
TRAIL NO. B-57 THETA
20 SEPTEMBER 1966
04 :03:00 A.S.T.

UPTRAIL ●

DOWNTRAIL ▲

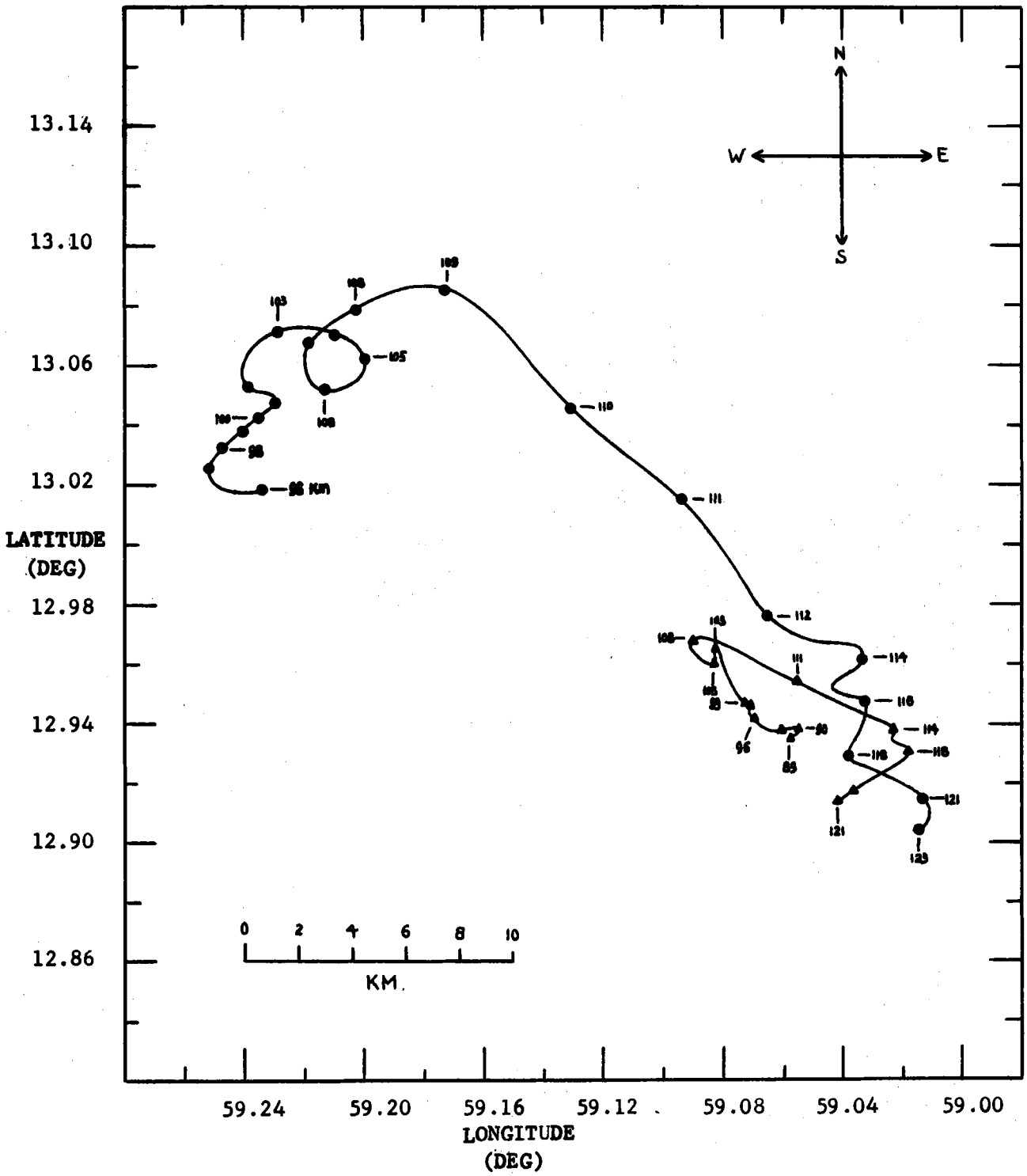


GROUND PLOT
T + 262

H.A.R.P. BARBADOS
TRAIL NO. B-59 BELFAST
15 FEBRUARY 1967
21:17:00 A.S.T.

UPTRAIL ●

DOWNTRAIL ▲

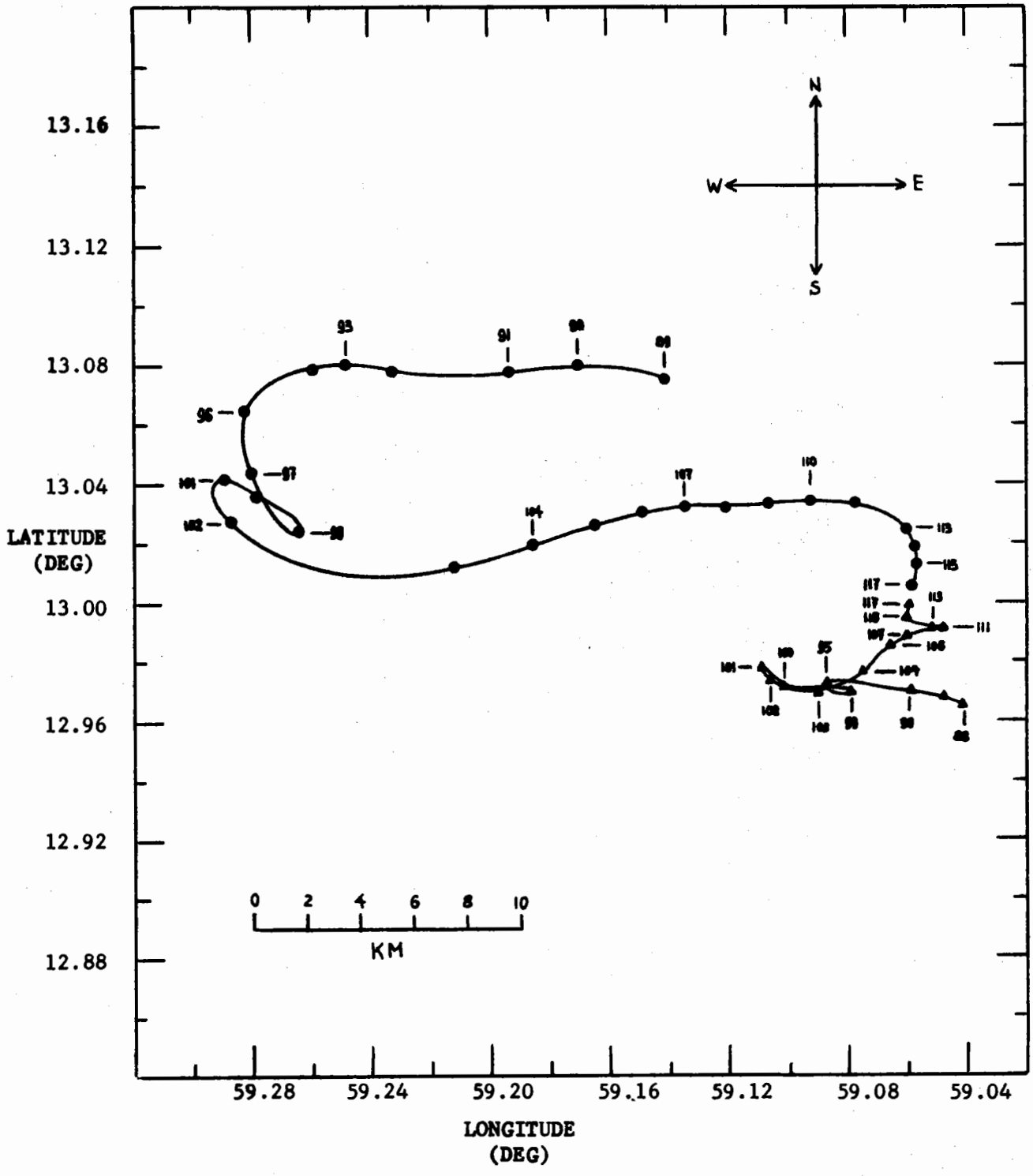


GROUND PLOT
T + 252

H.A.R.P. BARBADOS
TRAIL NO. B-61 DUBLIN
15 FEBRUARY 1967
23:56:00 A.S.T.

UPTRAIL ●

DOWNTRAIL ▲

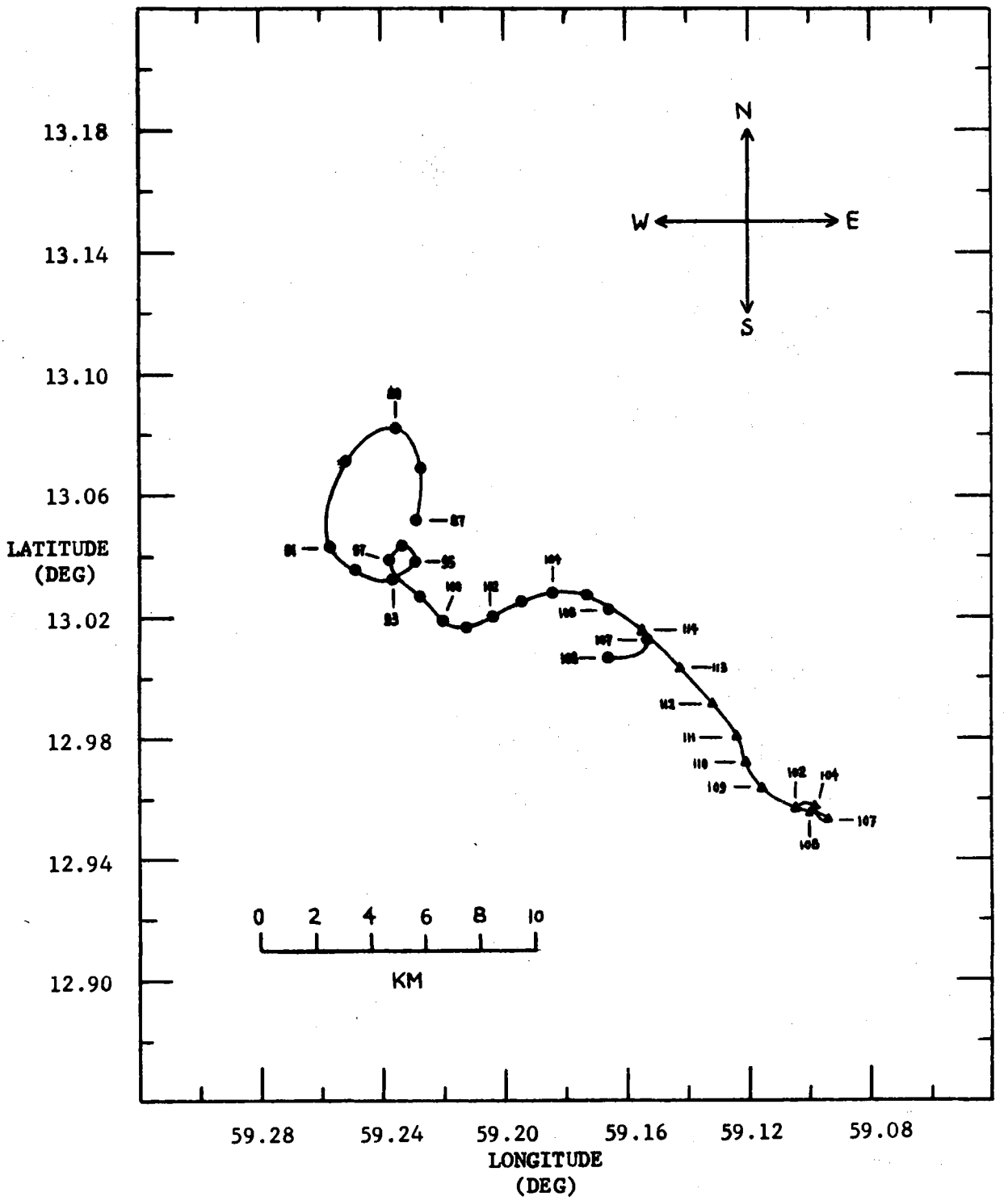


GROUND PLOT
UPTRAIL T + 172
DOWNTRAIL T + 252

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-63 HOLLYWOOD
16 FEBRUARY 1967
22:45:00 A.S.T.

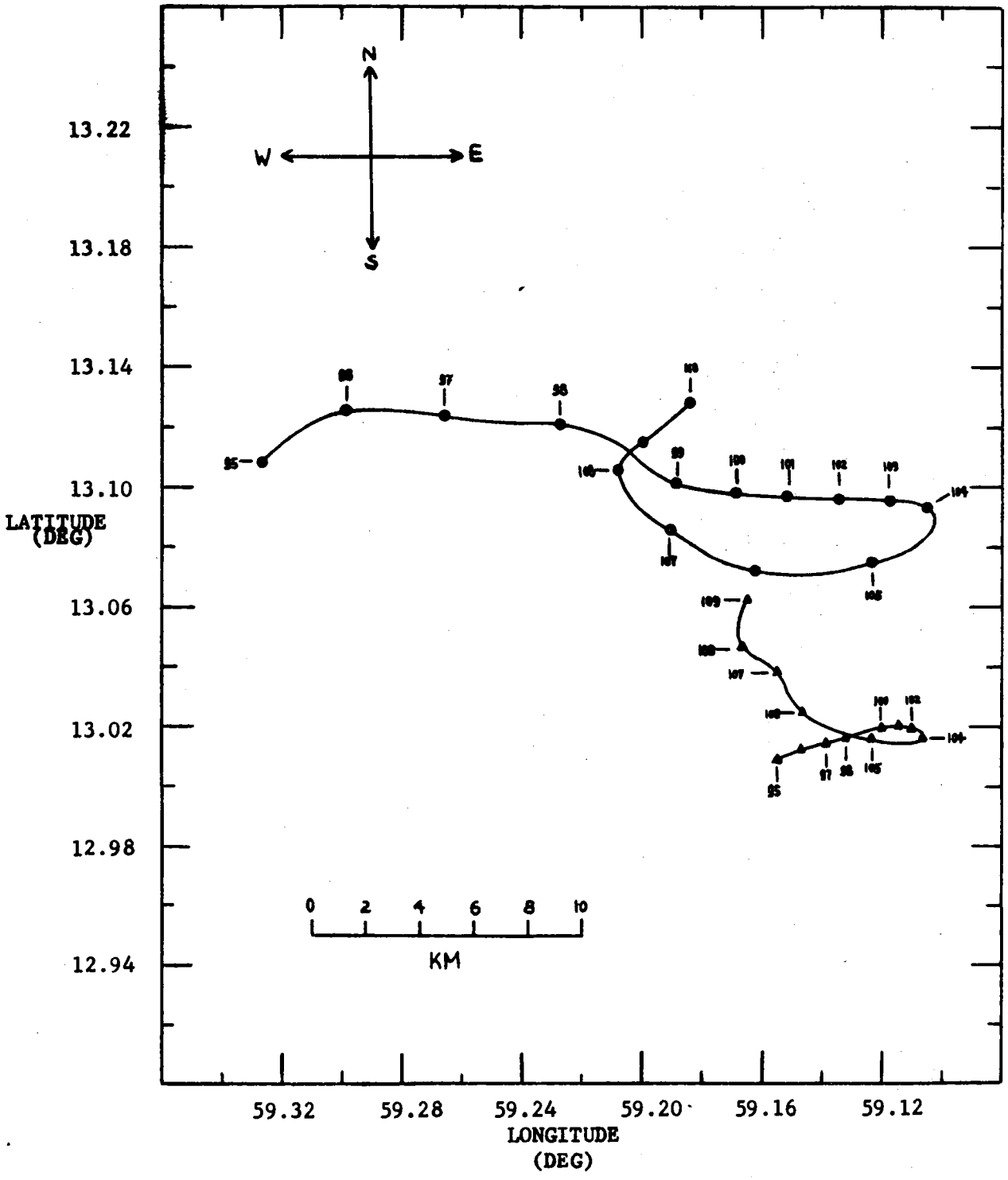


GROUND PLOT
T + 252

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-65 LIMERICK
16 FEBRUARY 1967
04:17:00 A.S.T.

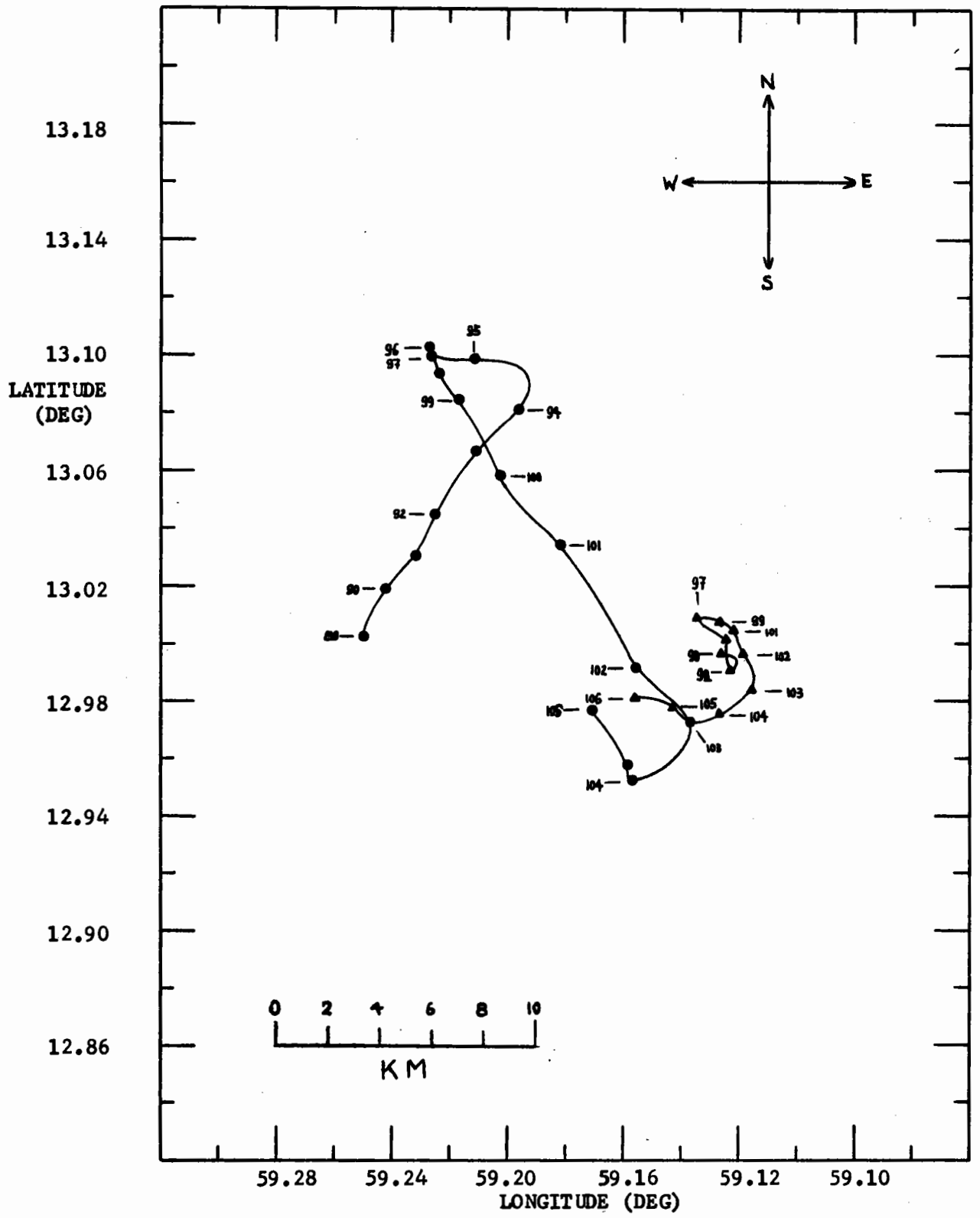


GROUND PLOT
T + 212 SECONDS

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. BARBADOS
TRAIL NO. B-67 CAIRO
21 JUNE 1967
22:47:00 AST

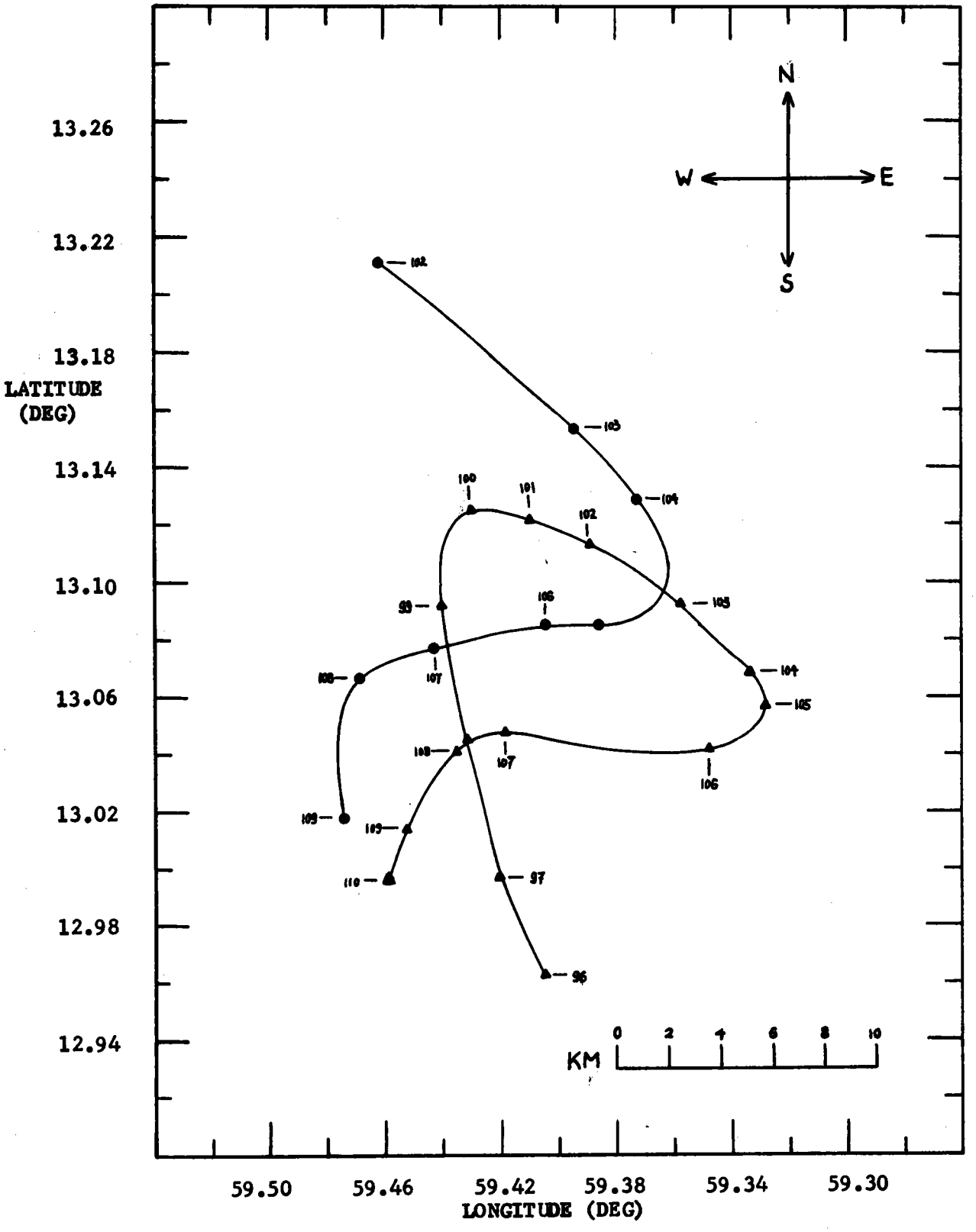


GROUND PLOT
T + 342 SECONDS

UPTRAIL ●

DOWNTRAIL ▲

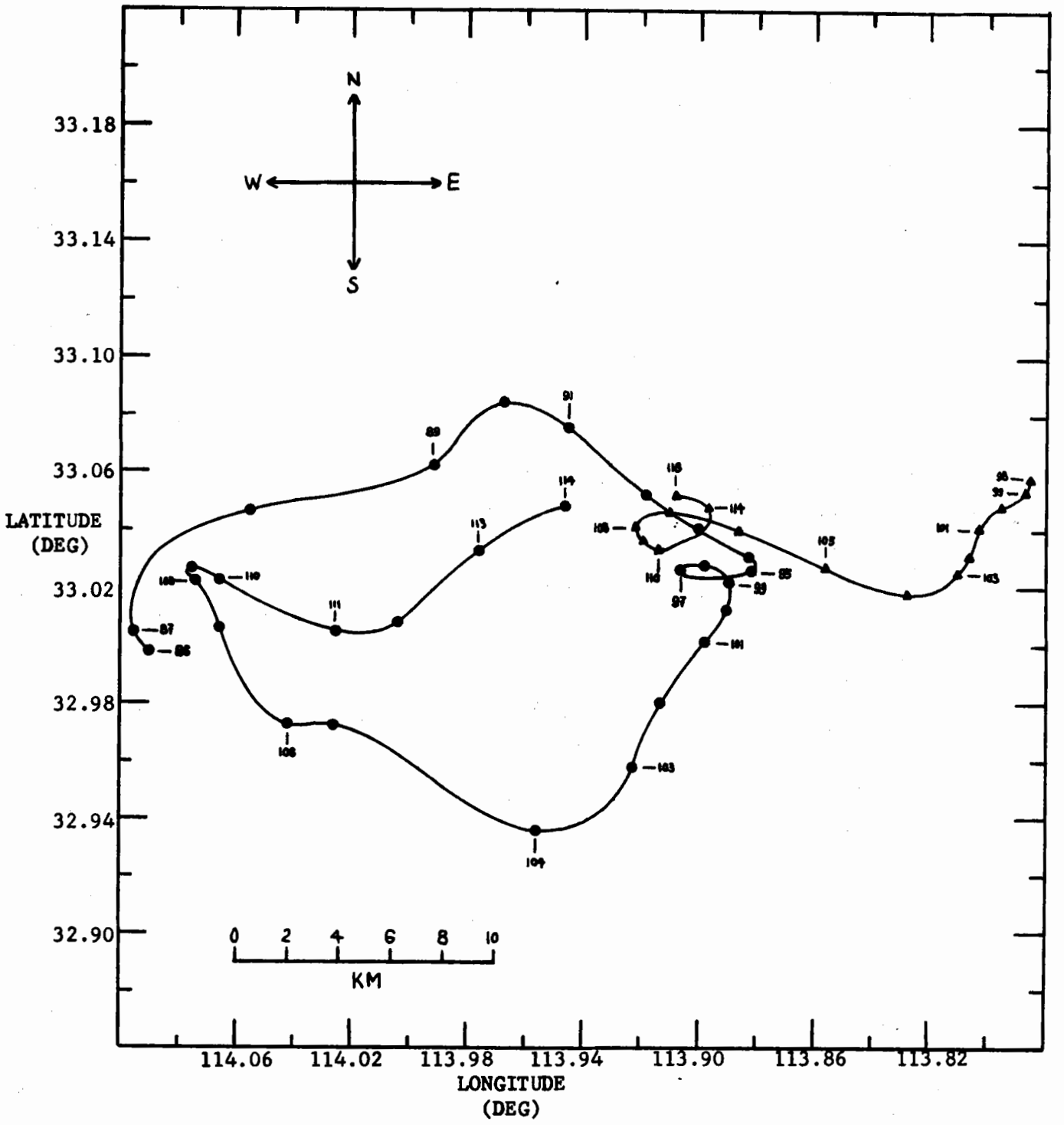
H.A.R.P. BARBADOS
TRAIL NO. B-68 DURBAN
22 JUNE 1967
19:51:00 AST



GROUND PLOT
UPTRAIL T + 262
DOWNTRAIL T + 272
UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. YUMA
TRAIL NO. Y-4 Mc CONNELL
15 JUNE 1966
01:27:00 A.S.T.

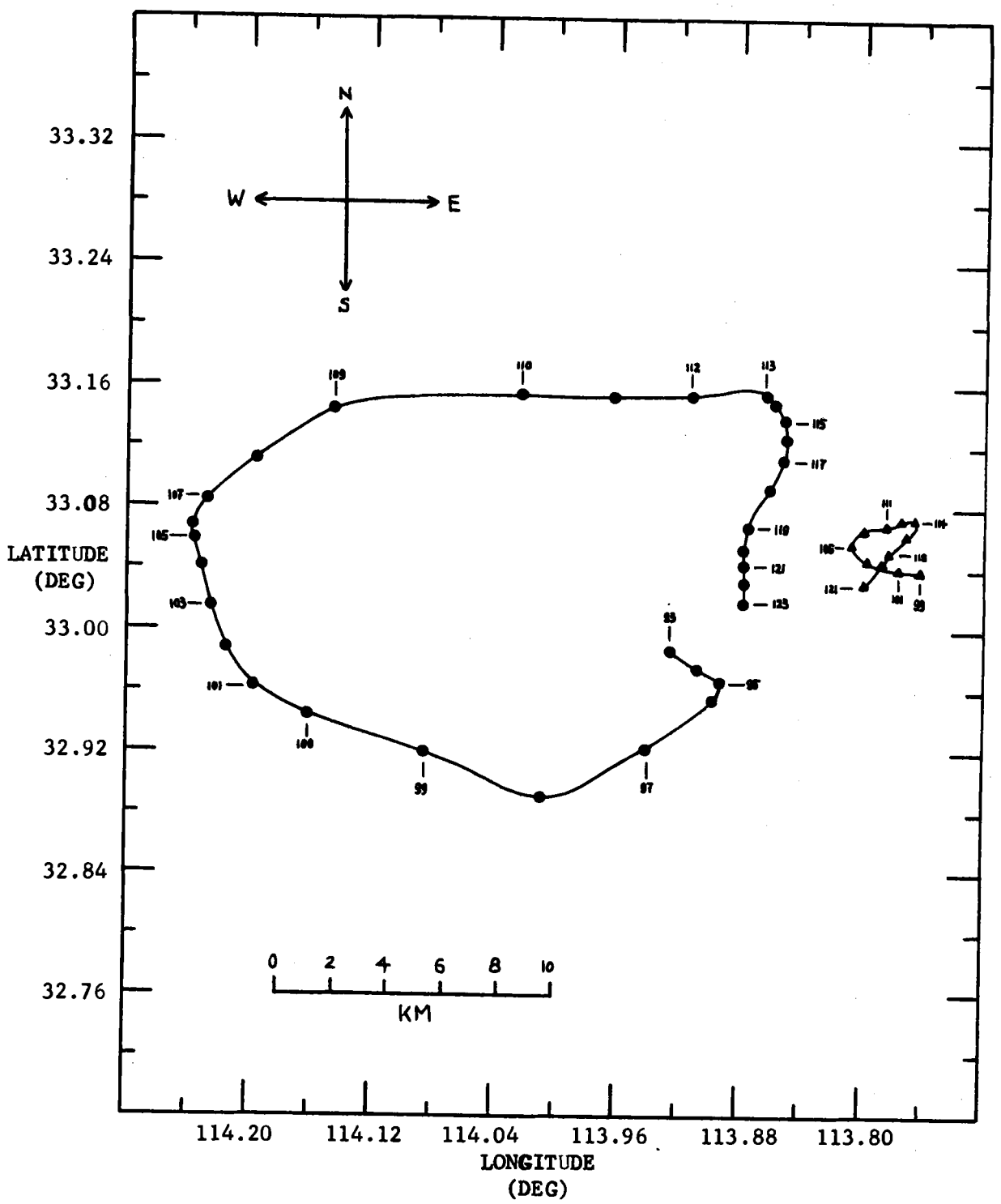


GROUND PLOT
T + 252

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. YUMA
TRAIL NO. Y-13 SHOT# 20
17 NOVEMBER 1966
00:16:13 A.S.T.

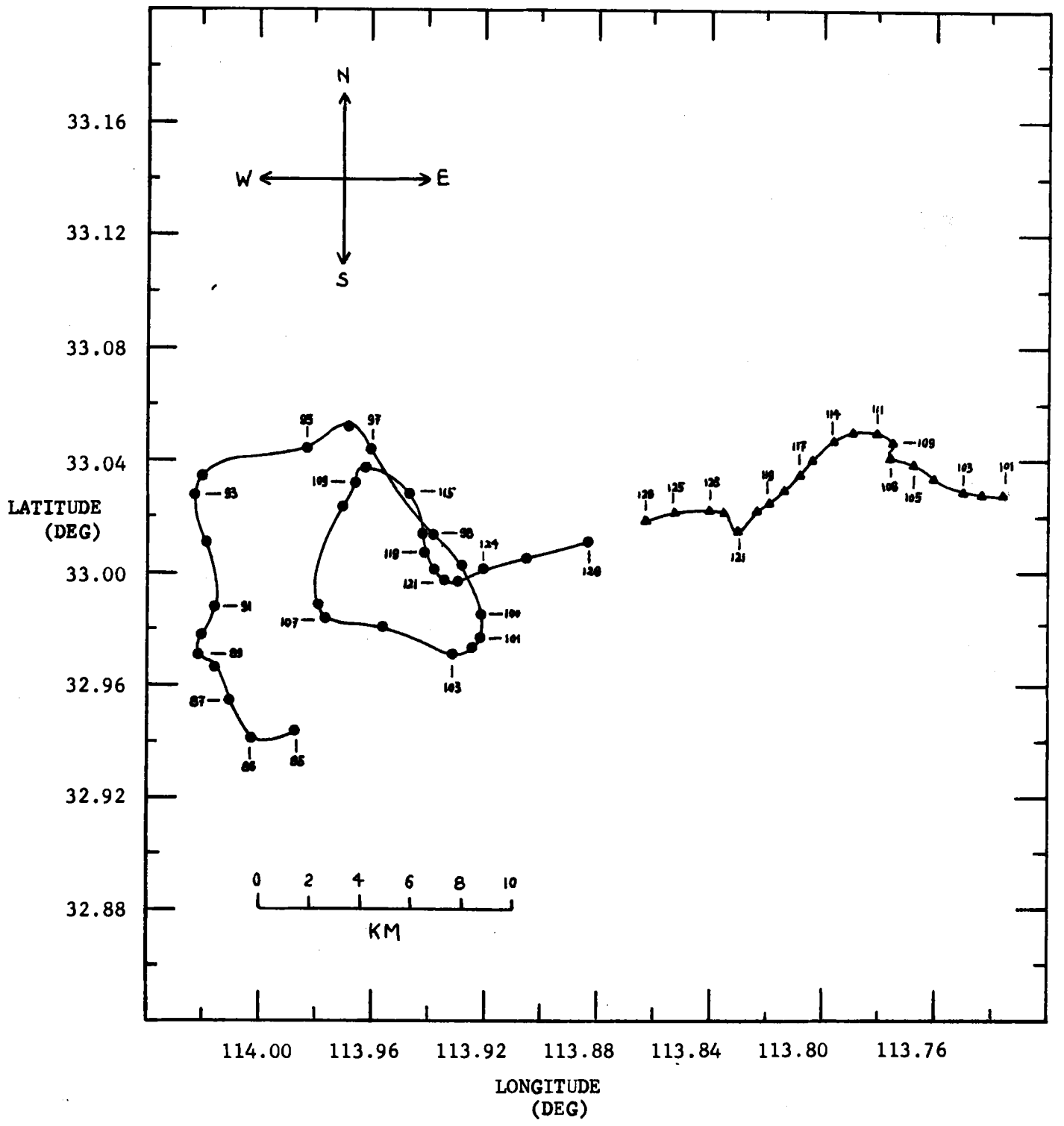


GROUND PLOT
T + 262

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. YUMA
TRAIL NO. Y-15 SHOT # 23
18 NOVEMBER 1966
20:12:21 A.S.T.

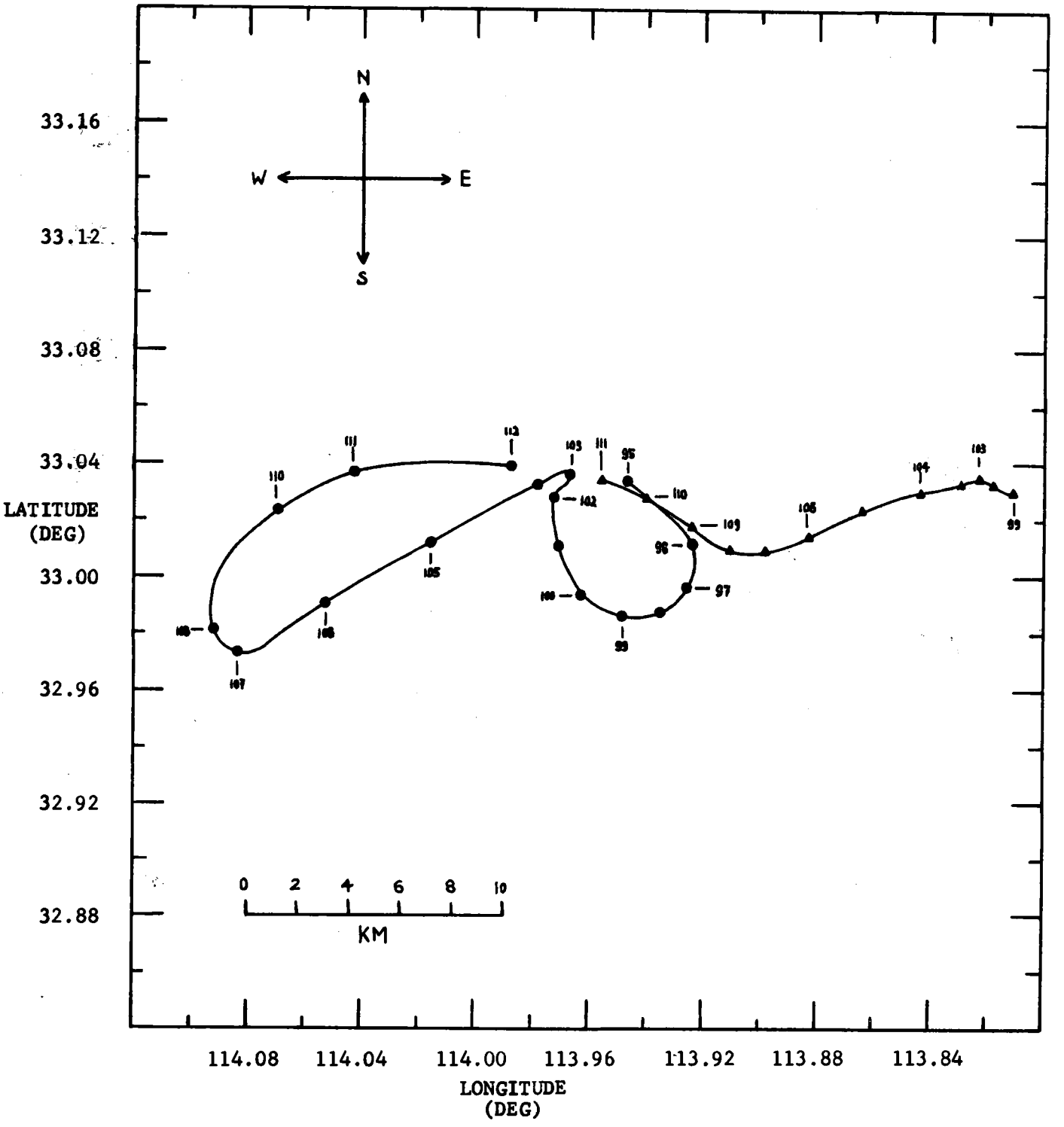


GROUND PLOT
T + 222

UPTRAIL ●

DOWNTRAIL ▲

H.A.R.P. YUMA
TRAIL NO. Y-22 SHOT # 31
19 NOVEMBER 1966
21:21:29 A.S.T.



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13. ABSTRACT

During the nights of 21-22 June 1967, two luminous trails were produced between 89 and 110km by the release of trimethyl aluminum from projectiles fired from a smoothbore sixteen-inch gun located on the West Indian island of Barbados (57.5°W, 13.1°N) and on the night of 12 June 1967 an additional trail was produced by a projectile fired from a similar sixteen-inch gun located at Yuma, Arizona (114.3°W, 32.9°N). These trails were photographed from neighboring sites and analyzed to yield wind profiles. This report contains the tabulated wind data from all three trails together with plots versus altitude of wind components, wind speed, and wind heading. Included in this report are ground plots of trails for all previous shots that had both an up trail and a down trail.

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